INVESTIGATION OF VARIOUS NAVIGATION SYSTEMS THAT WOULD BE COMPATIBLE TO THE TASES AIRCRAFT

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THESIS

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TO THE TASES AIRCRAFT

by

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TASES (Tactical Airborne Signal Exploitation System) will modify the basic S-3A avionics system to perform an open ocean fleet support electronic mission. Navigation of the aircraft will be performed by the pilot using systems that were designed for an ASW mission and dual piloted aircraft.

The addition of an automatic Omega tracking receiver would ease the burden of navigation in the event of primary

system failure. The pilot/navigator would be provided a reliable and accurate world-wide fixing device that would augment the basic navigation system. A relative fixing scheme could also be incorporated, using the Omega system that would provide accurate ranges and bearings of reported targets at distances exceeding 250 nautical miles.

Investigation of Various Navigation Systems that Would be Compatible to the TASES Aircraft

by

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TASES (Tactical Airborne Signal Exploitation System) will modify the basic S-3A avionics system to perform an open ocean fleet support electronic mission. Navigation of the aircraft will be performed by the pilot using systems that were designed for an ASW mission and dual piloted aircraft.

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I. INTRODUCTION

A. TASES CONCEPT

The TASES (Tactical Airborne Signal Exploitation System) concept will employ the basic S-3A Viking airframe and alter the electronic package to perform an open ocean fleet support electronic surveillance mission. The proposed navigation suite for this new version is identical to that of the S-3A, even though a different mission will be performed. In the S-3A system the co-pilot is responsible for navigation of the aircraft; the TASES concept will place the added burden of navigation on the pilot since the right seat will be occupied by an ELINT operator.

The platform will be required to supply DF and emitter location data on a real time basis to the fleet. This places stringent requirements on the navigation package, because for this information to be useful, the aircraft's geographical position or relative position must be accurate, especially if the platform is to act in a target acquisition role.

The ASW problem as faced by the S-3A requires accurate short-term navigation. Updates of the system in open ocean could be accomplished by overflights of sonobuoy arrays to provide short-term relative fixing. The acquisition and tracking are done within the aircraft, so relative position of the aircraft to its sonobuoy array is of prime importance.

The ELINT problem requires the platform to locate threat targets and relay their location to some coordinator. Therefore, its navigation suite should have long-term accuracy or some ability to report emitter location and targets relative to the coordinator.

B. MISSION VARIATIONS

The TASES aircraft will be required to fly a variety of mission profiles, from close-in fleet support to stand-off coastal surveillance missions.

1. Carrier Oriented ELINT Collection and Surveillance (0 - 200 nm)

This profile would remain within 200 nm of the aircraft carrier. TACAN and internal fixing devices such as inertial or doppler/air mass would provide fixing information. However, if EMCON conditions existed, the aircraft would have to rely entirely upon internal navigation.

The S-3A navigation suite has two internal devices that provide positive fixing information: Search Radar and an Inertial Navigation System. A third system, the GPDC Navigation Subprogram provides dead reckoning information. In the TASES version the pilot/navigator will not have direct access to the radar and no airframe modification is provided for a repeater scope. Thus normal fixing information to the navigator is supplied by only one system, the inertial navigator.

2. Carrier Support beyond 200 nm

These missions will extend beyond the 200 nm TACAN range where the navigation will be conducted entirely within the aircraft in an open ocean environment. Normal fixing methods will exist entirely within the CAINS Inertial Navigation System. The accuracy of the system will depend upon the initial alignment prior to departure and the successful operation of any peripheral devices that damp the system such as the doppler radar. Loss of the inertial navigation system would place the entire system into a dead reckoning mode of operation, using the GPDC Navigation Subprogram.

3. Stand-off Coastal Surveillance

This mission profile would place the collection platform at some predetermined distance from a coastline for purposes of detection and location of RF emitters. These types of missions are very sensitive with respect to navigation. Accidental overflights of land masses or violation of national airspace may precipitate grave political consequences. In hostile environments, the aircraft must be able to successfully avoid the kill envelope of enemy missiles.

The normal mode of navigation in this profile will still be the CAINS system; however, periodic updates of the GPDC Subprogram System can be accomplished by using the aircraft radar. This would require the ELINT operator to perform some navigational functions as the pilot has no radar controls or repeater at his disposal. The frequency

of those updates would be at the pilot/navigator's discretion. If flight conditions were such that the land mass was visible, fewer checks or updates of the system would be necessary than if the aircraft was flying above an overcast.

Any loss of the inertial system in this profile would place the system in a dead reckoning mode. However, periodic updates of the dead reckoning system with the use of radar would provide good short-term navigation. This would degrade the collection ability of the ELINT position.

C. AIRCRAFT NAVIGATION SYSTEMS

There exists a wide variety of aircraft navigation systems ranging from simple dead reckoning devices to highly sophisticated inertial navigators. A few of these systems, such as radar, TACAN, and inertial navigators, lend themselves readily to the ELINT navigation problem.

The basic S-3A navigation system contains a search radar system, inertial navigator, TACAN and a General Purpose Digital Computer Subprogram that is essentially a dead reckoning navigation device.

1. TACAN

TACAN is the primary navigation aid for carrier based aircraft when operating in the vicinity of the carrier. It is an RF fixing device that places the aircraft at a range and magnetic bearing from the transmitting site. It is range limited to 200 nm for distance measurement.

An altitude restriction is also placed on the aircraft as line-of-sight transmission of the TACAN signal is required. The approximate distance the TACAN is usable for any given altitude is given by the formula, $d = 1.2\sqrt{h}$, where d is the distance in nautical miles and h is the altitude of the aircraft in feet. Figure 1 shows the solution for the formula $d = 1.2\sqrt{h}$. For reception of the TACAN signal the aircraft must locate itself within the shaded region of the altitude/distance curve. If the aircraft is 150 nm from the carrier, its minimum altitude for successful reception is approximately 15,600 feet.

Maximum expected errors for TACAN are ±2000 feet in DME and ±2° in azimuth [Ref. 1]. The maximum range error will essentially remain constant to 200 nm. The azimuth error of the TACAN will cause the bounded position error of the aircraft to get larger as the range from the TACAN station increases. Thus the area the aircraft could be located in increases as the distance from the station increases. The shaded areas of Figure 2 reveal how the area increases with range. The area of these shaded portions is given by:

$$A = \int_0^{r_2} \int_0^{\theta} r\,dr\,d\theta - \int_0^{r_1} \int_0^{\theta} r\,dr\,d\theta = \frac{\pi}{180} (r_2^{\,2} - r_1^{\,2})$$

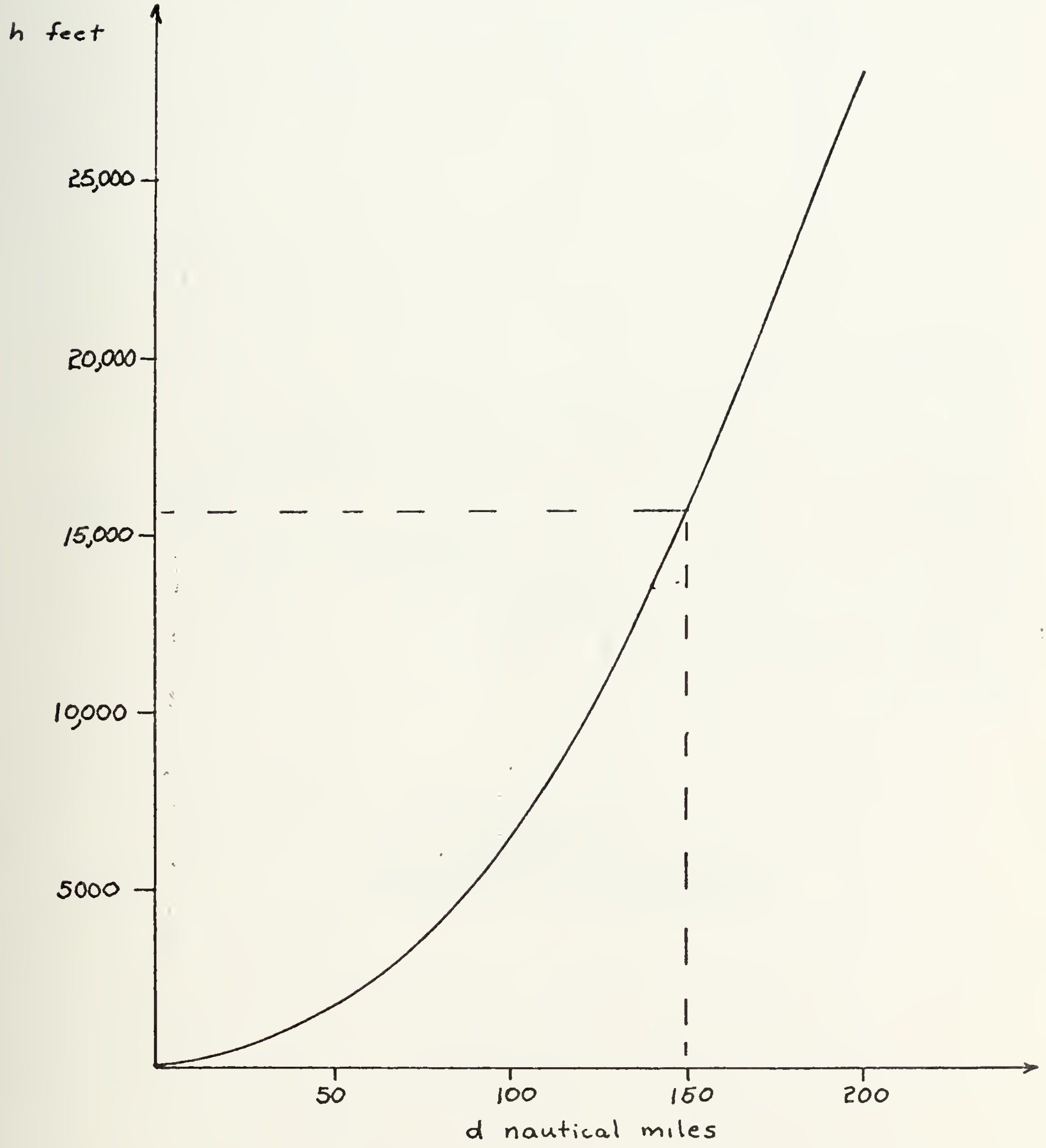


Figure 1

Range vs. Altitude for Reception of Line of Sight RF Transmissions

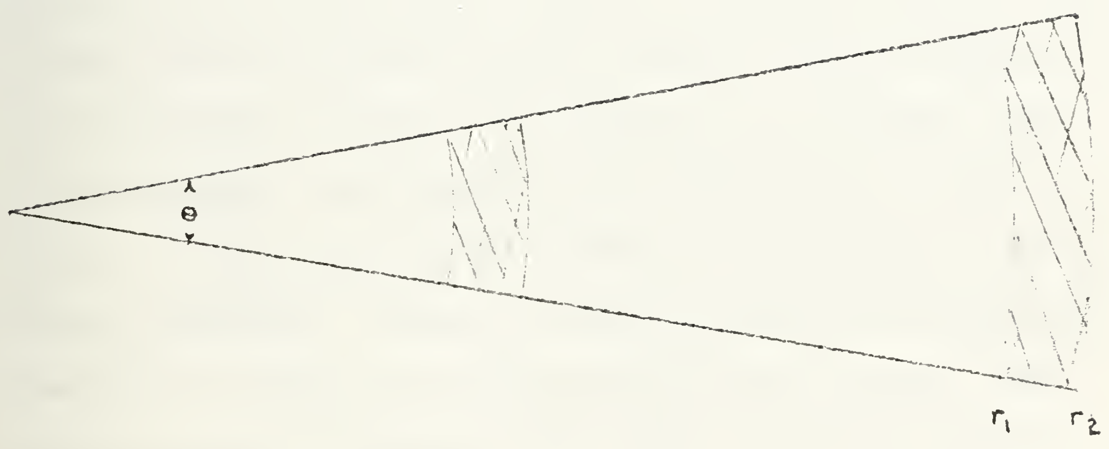


Figure 2
TACAN Error in Position

At 200 nm using maximum DME error (±2000 feet) and maximum azimuth error ±2°, the area is approximately 4.6 square miles.

2. Inertial Navigators

Inertial navigators have improved greatly in both accuracy and reliability during the past few years. An ELINT platform, out of radar range, can remain covert since there are no RF emissions. However, barring any update of the system, accuracy of inertial systems does degrade with time. Some inertial navigators such as the CAINS system use the aircraft's doppler radar system to velocity damp the inertial platform for increased long-term accuracy. By doing so, the RF silence no longer exists. CAINS does have the ability to navigate without doppler damping. Figure 3 shows the effects of velocity damping to those of an undamped inertial system. The damping tends to decrease the amplitude of the Schuler oscillations and to decrease the rate of accumulated error.

Inertial alignment of inertial navigators is extremely important for accurate operation. Alignment ashore is greatly simplified since the aircraft is not moving with respect to the earth. However, aboard an aircraft carrier, the motion of the inertial platform with respect to the earth must be considered for successful alignment. Accurate position, attitude and velocities must be supplied from the carrier's navigation system for the inertial platform to achieve proper alignment.

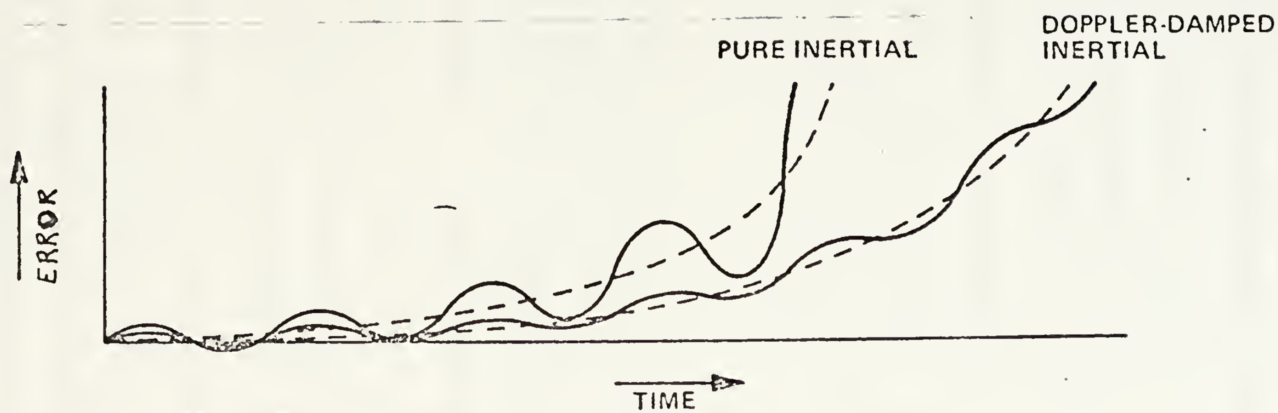


Figure 3

Pure vs. Doppler - Damped Inertial Error

Some inertial navigators have the capability for inflight alignment, but a known geographical point must be overflown. This process requires many minutes of straight and level flight and an operating doppler radar system.

Considering proper alignment and velocity damping, inertial navigators can attain better than 1 nm/hr accuracy. Thus with no updates in position to the system, a 1 nm/hr system can be expected to accumulate a 5 nm discrepancy in position after five hours of flight time. The aircraft could be located within a- area as large as 79 square miles after five hours of flight.

3. Radar

Radar is perhaps the most positive and accurate fixing device available to aircraft. However, to obtain radar fixes, identifiable landmarks must be present within the radar range. Accuracies of better than 1000 feet in geographical locations are possible depending on type of radar and chart accuracy [Ref. 1]. Unfortunately, the radar system aboard the TASES aircraft is not available to the pilot/navigator. If a need arises for radar fixing the ELINT operator in the right seat must perform this function. Thus any update of the basic navigation system by radar on a coastal surveillance mission must be performed by the ELINT operator.

4. Doppler and/or Air Mass Navigators

The Doppler Radar/Air Mass Navigation Systems are essentially dead reckoning devices. No long-term accuracy

can be expected without repeated updates of actual position. Accurate ground speed and drift information is supplied from the doppler radar to a computing system. True air speed and heading is supplied to the computing system from aircraft sensors. Aircraft position is then computed from the last position. Any loss of the doppler information places the system in a memory mode and the last information supplied by the doppler system is used. The accuracy of this system is dependent upon the accuracy of the heading information, magnetic variation, doppler and air speed sensor combined. Although this system is useful, it lacks the accuracy for a long-term mission.

5. Omega System

The Omega System is discussed in detail in the appendix of this thesis. The accuracy of this system is projected to be approximately 1 nm daytime and 2 nm at night [Refs. 2, 3, and 4]. Other variations of this system such as Relative Omega and Differential Omega could yield accuracies of .15 nm to .6 nm [Ref. 5]. The Relative and Differential Omega systems offer some intriguing advantages to carrier aircraft fixing schemes that could greatly enhance the solution of target location.

6. Other Systems

There are many other systems that are in use today that lend themselves to aircraft navigation such as LORAN and DECCA, but these systems do not provide world-wide coverage. The navigation suite for TASES should be

usable at any geographical locationthe carrier might operate.

II. THE BASIC TASES NAVIGATION SYSTEM

A. S-3A NAVIGATION SYSTEM

The proposed navigation system for TASES is identical to the navigation system now available on the S-3A aircraft. Figure 4 shows a block diagram of the S-3A navigation system. Navigation is accomplished by two complete and independent systems, the Inertial Navigation Systems (INS) and the GPDC Navigation Subprogram. Of these two systems, only the INS is a positive fixing device; the GPDC Navigation Subprogram is essentially a digital dead reckoning device. The aircraft also contains a search radar (not controlled by the pilot/navigator) and standard avionics systems such as TACAN, ILS and ADF. The TACAN, ILS and ADF systems facilitate navigation about the carrier and land-based facilities.

1. Carrier Aircraft Inertial Navigation System (CAINS)

CAINS was designed to overcome some of the prior maladies of carrier aircraft inertial navigators and to offer some uniformity to ease maintenance problems aboard carriers. Short erect times, data link alignment and improved accuracy are major areas of improvement.

Required alignment times have been reduced by more than a factor of two by using new filtering and processing techniques. This has greatly improved the reaction time in launching aircraft from the carrier.

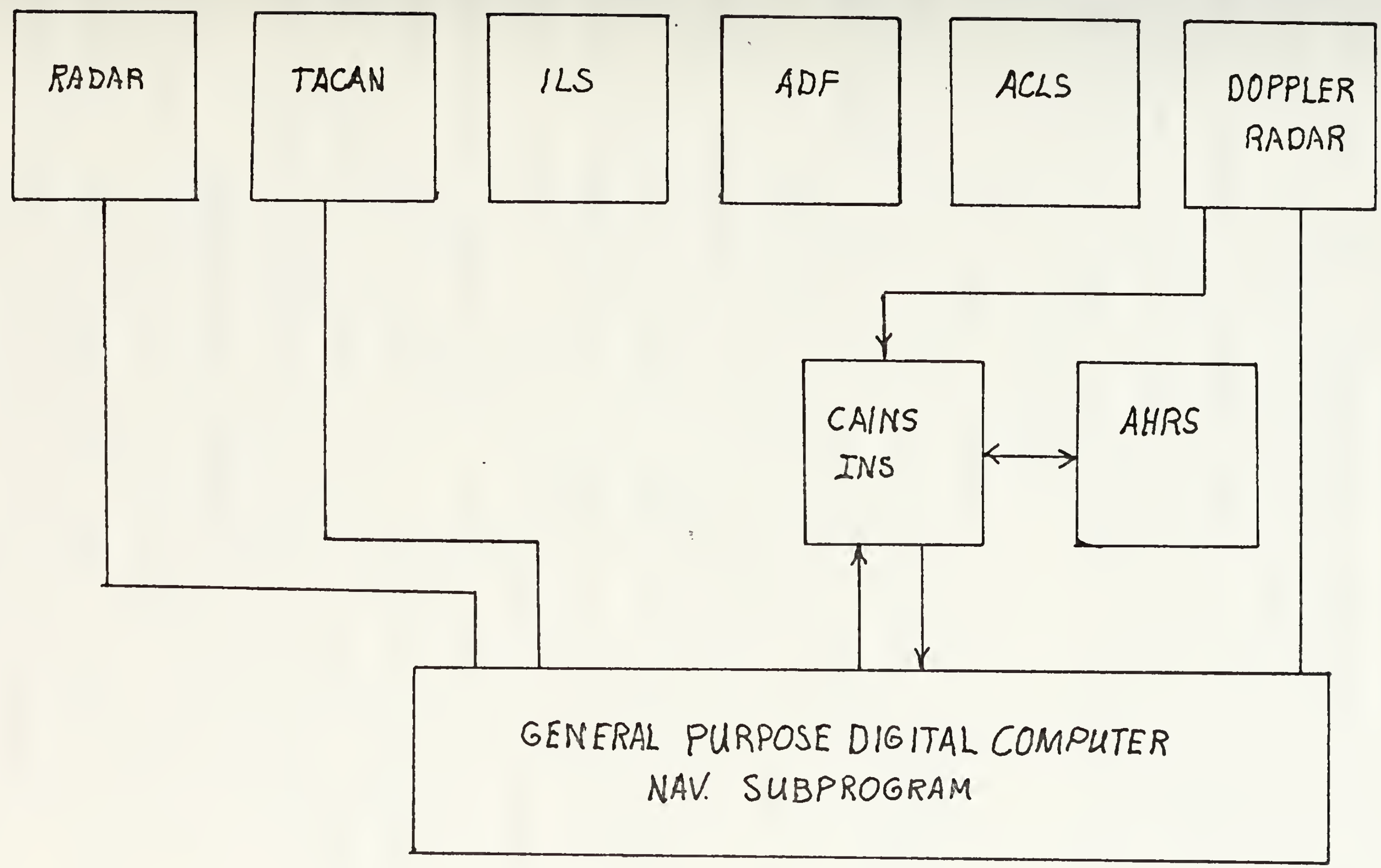


Figure 4
Block Diagram of S-3A Navigation System

The data link alignment system allows the aircraft to be moved during some stages of alignment, thereby offering greater flexibility in spotting aircraft on deck. Prior to the data link, aircraft were attached to an umbilical cable for alignment inputs from SINS; this capability is still retained. Improved gyros and accelerometers plus a technique to velocity damp the system has led to improved accuracies over past carrier based aircraft navigators.

a. System Components

The basic components of the CAINS system are a power supply unit, flux valve, airborne navigation computer unit (ANCU), and an INS converter (Figure 5).

The Inertial Measurement Unit (IMU) senses aircraft movement in any direction and produces acceleration and attitude signals which are relayed to the ANCU, a self-contained general purpose digital computer. It has the necessary control logic, memory, arithmetic, and input/output capability to perform mode control, inertial alignment, and the required navigational computations. ANCU operation is controlled by a computer program which was specifically designed for the S-3A mission.

Information exchange to and from other systems is provided through the INS converter. This unit stores, transfers, and processes data into a format compatible with circuits of the associated equipment (Figure 6).

The navigation control panel contains all the manual switches and displays associated with the system.

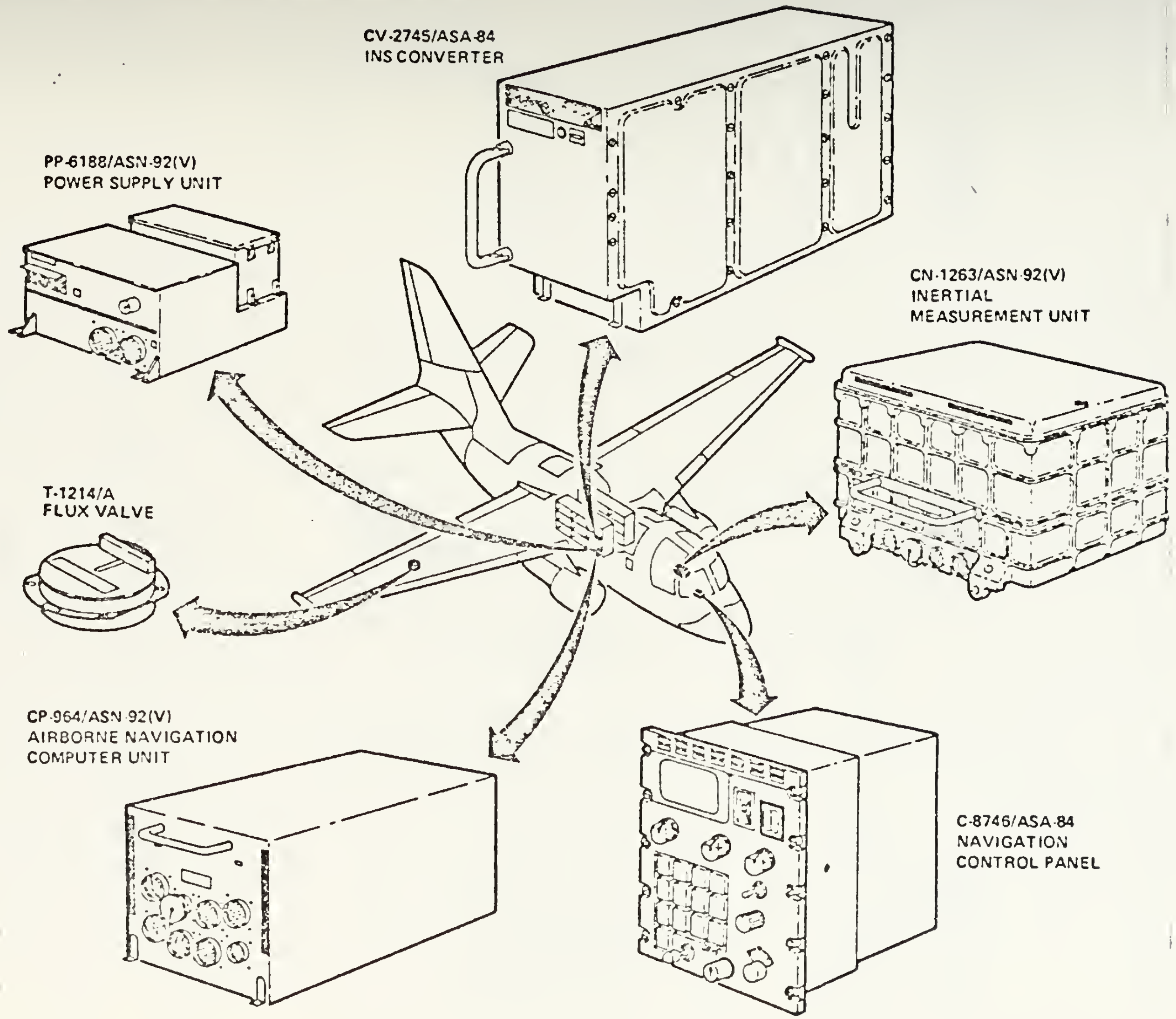


Figure 5
Inertial System Components

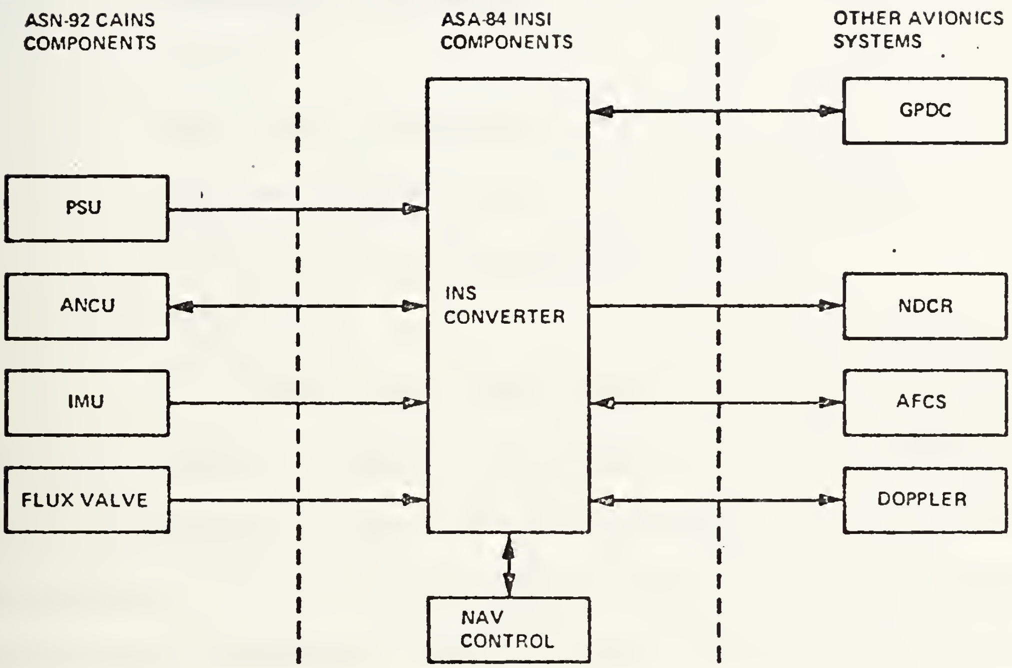


Figure 6
INS Converter Simplified Block Diagram

Information from the ANCU is selected and displayed on this panel. The following navigation parameters can be displayed:

True heading

True track

Ground speed

Current aircraft latitude and longitude

Magnetic variation

Wind

Way point positions

Range and bearing to destination point

Time to go to destination point

b. Operation

The ANCU uses three basic velocity sources: inertial, doppler and true airspeed. It will automatically switch from inertial velocities to doppler velocities upon IMU failure. If the doppler velocities are also unavailable, it will then switch to true airspeed and operate in an air data mode.

In the doppler damped inertial mode, the inertial measurement of aircraft acceleration plus doppler velocity is used to produce all navigational outputs. Doppler velocities are used to dampen the inherent errors of the inertial platform. Operation in this mode is accurate at any latitude, since magnetic heading information is only used for calculating variation.

If doppler velocities are unavailable, the system switches to pure inertial navigation. All navigation

parameters are computed from inertial inputs. This mode of operation is also accurate at any latitude.

Loss of the inertial measuring unit (IMU) will place the system in either the doppler mode (if operating) or air data mode in that order of precedence. Doppler navigation utilizes doppler velocities, estimated magnetic variation, and magnetic heading supplied by the inertial platform operating as a magnetically slaved, gyro-stabilized compass. Doppler navigation is only accurate at latitudes less than 70°N or 70°S since magnetically slaved heading information is unreliable in the Polar regions.

Air data navigation will occur if both the IMU and doppler systems become inoperative. This mode utilizes true airspeed, stored wind data and magnetically slaved, gyro-stabilized compass inputs. This system also is not accurate above latitudes 70°N or 70°S for the same reasons as previously described.

2. General Purpose Digital Computer Navigation Subprogram

The GPDC Navigation Subprogram is a completely independent navigation system. Since the system does not perform any navigation measurements, it is essentially a digital dead reckoning system. It performs two basic functions; it maintains a continuous dead reckoning position for the aircraft and assists the operator through a series of tactical plot display options.

Inputs from the doppler radar, true airspeed sensor, attitude and heading reference set (AHRS) and INS are utilized within the system. The navigation subprogram uses these inputs to compute aircraft position 20 times a second, and displays this position within the navigation parameters tableau as a latitude and longitude and within the tactical plot as an aircraft symbol.

The navigation subprogram position can be updated by overflights of known landmarks or from TACAN or radar fixes.

B. ADVANTAGES

1. Passive Operation and Immunity to Jamming

The inertial navigator, when not doppler damped, is a passive navigation device. Unlike RF fixing devices, the system is totally contained within the aircraft and is immune to any outside interference.

2. Global Operations

Operation at any point on the globe is possible with the INS system. Inertial platforms are immune to any variations in the magnetic field.

3. Short Erect Time and Data Link Alignment

Improved filtering processes have decreased the time required to align the INS system. This along with data link alignment has greatly relieved the problem of handling aircraft on a crowded aircraft carrier deck.

C. DISADVANTAGES

1. Cross Reference

In an open ocean environment, no other positive fixing device is contained within the aircraft to check the inertial navigator. In areas of operation where radar fixes can be taken the GPDC subprogram can be updated, but this must be accomplished by someone other than the pilot/navigator.

2. Lack of Backup Fixing Device

If the IMU or any part of the inertial navigator failed the aircraft would not have any means to positively fix itself. The GPDC subprogram and the functions the ANCU performs upon IMU failure are nothing more than dead reckoning devices.

3. The Risks

The S-3A navigation system was designed for an ASW mission and for a two piloted aircraft. One of the primary functions for the co-pilot was navigation. The TASES version will place the added burden of navigation upon the pilot using essentially the same navigation system and a different mission. As yet, the success of the navigation system in fleet operations has not been determined. Even if the navigation system is proven adequate for ASW type missions, optimum navigational capabilities for single piloted ELINT profiles are not necessarily assured.

III. BASIC TASES NAVIGATION SYSTEM PLUS OMEGA

A. OVERVIEW

Since the pilot does not have access to the aircraft's radar for fixing purposes, he is limited to the remaining navigation devices of the basic suite, CAINS, computer/doppler, and airmass. His only cross references for position exist between these three systems, two of which are essentially dead reckoning devices. Thus any loss of the primary system (CAINS) would place the navigation system in a dead reckoning mode. If the aircraft is operating in an area where radar fixes are available, the ELINT operator could update the GPDC subprogram. This would require some navigation expertise on the ELINT operator's behalf and would certainly degrade the collection capability of that position.

With the addition of an aircraft automatic Omega tracking receiver, the flexibility of the navigation suite can be increased. The pilot would have a completely independent navigation system for cross reference that would give him all the information the basic system yields, latitude and longitude read-out, ground track vector, wind vector, and estimates of range, flight time and steering corrections to inserted way-points.

B. SYSTEM OPERATION

Various airborne Omega receiving sets are presently available and improved models will be appearing as the Omega system approaches full operation. Only the basic operation of the AN/ARN - 99(V)2 Omega set will be discussed in this paper. Flight tests were conducted on this system and one other, the AN/ARN - 115, in 1972. At the time of the tests only four Omega stations were transmitting, all of which were transmitting at less than design power.

1. AN/ARN - 99(V)2 Omega Receiving Set

This system provides fully automatic display of the aircraft's geographic latitude and longitude coordinates, and supplies read-out information for ground track and wind vector. It furthermore provides estimates of range, flight time, and steering corrections to definable way-points.

This set is capable of receiving all three Omega frequencies (10.2, 11-1/3, and 13.6 KHz) from all eight stations concurrently, and through the use of Kalman filtering determines a statistically optimum position. A programable general purpose computer is used to automatically compute and apply diurnal propagation phase corrections to the measured phase information.

Since the aircraft is moving with respect to the Omega stations, the aircraft's velocity vector must be considered to compensate for any phase shift due to doppler effects. The vehicle's true airspeed and doppler radar, and heading sensors supply this information. Depending on

the wind vector, true airspeed alone could be used with little loss in system accuracy; thus the system is versatile in its requirement for velocity vector information. This information is also used to provide dead reckoning position in the event of Omega signal loss.

Lane widths of 72 nautical miles will exist when using a three-frequency receiver [Ref. 4]. Thus the aircraft must know its position within ±36 nm prior to system operation. Thereafter the system automatically keeps track of lane crossings. In the event of complete Omega signal loss, the system will degrade to a dead reckoning mode and compute all read-out parameters until usable Omega signals are again received. A difference frequency lane ambiguity resolution algorithm allows recovery from position errors of up to 36 nm.

2. System Accuracy

Various flight profiles and track locations were flown to evaluate the AN/ARN - 99(V)2 and ARN - 115 systems. Figure 7, taken from Ref. 6, shows the comparative position error fixes of the two systems. The operation of the AN/ARN - 99(V)2 system was not optimum as it had the capability of deriving fix information from eight Omega stations and reception from only four stations, and in some instances only two and three stations were obtainable. The AN/ARN - 115 has the ability to receive three stations. When the Omega system is fully operational and operating at design 10 Kw power, it is expected that at least six stations will

	ARN-99(V)2	ARN-115	Units
Principal Axes (Independent Variances):			
Major Axis Direction CW from North	000	044	deg
Major Principal Axis Standard Deviation	1.38	1.39	nmi
Minor Principal Axis Standard Deviation	0.86	0.78	nmi
Ellipticity	0.38	0.44	
Radial Error:			
Root-Mean-Square	1.89	1.80	nmi
50th Percentile (CEP)	1.07	1.44	nmi
75th Percentile	1.91	2.20	nmi
90th Percentile	2.42	2.81	nmi
95th Percentile	2.61	3.11	nmi
Maximum	8.92	4.39	nmi

Figure 7

Flight Test Accuracy of Two Airborne Omega Receivers

be receivable at any location on the globe. The reception of these added stations along with improved estimates of the diurnal propagation phase corrections should further enhance the fixing accuracy of the system.

C. EXTENSION OF OMEGA FOR RELATIVE FIXING

The incorporation of an Omega system aboard TASES could offer an attractive relative fixing scheme within 300 nm of the aircraft carrier. VLF propagation variations about a given point (200-300 nm radius) located at great distances from Omega transmitting sites are very nearly the same [Refs. 7 and 8]. This is to say that two sites located within 300 nm and using the same Omega stations for fixing purposes will experience approximately the same offset error of the uncorrected signals.

1. Relative Omega Geometry

Figure 8 shows positions P_1, P_2 and P_3 along with the uncorrected Omega fix Ω_1, which is associated with position P_1. The uncorrected Omega fixes for P_2 and P_3 are shown as circles because of their uncertainty in position. An observer at P_1 knows with a high degree of certainty that the observers at P_2 and P_3 will have uncorrected Omega fixes falling within the areas of Ω_2 or Ω_3 if they are using the same Omega stations for fixing purposes. The RMS error in the position of P_2 or P_3 could range from .15 nm to .6 nm and in general increases as the P_2 and P_3 are moved to greater distances from P_1. Thus the position

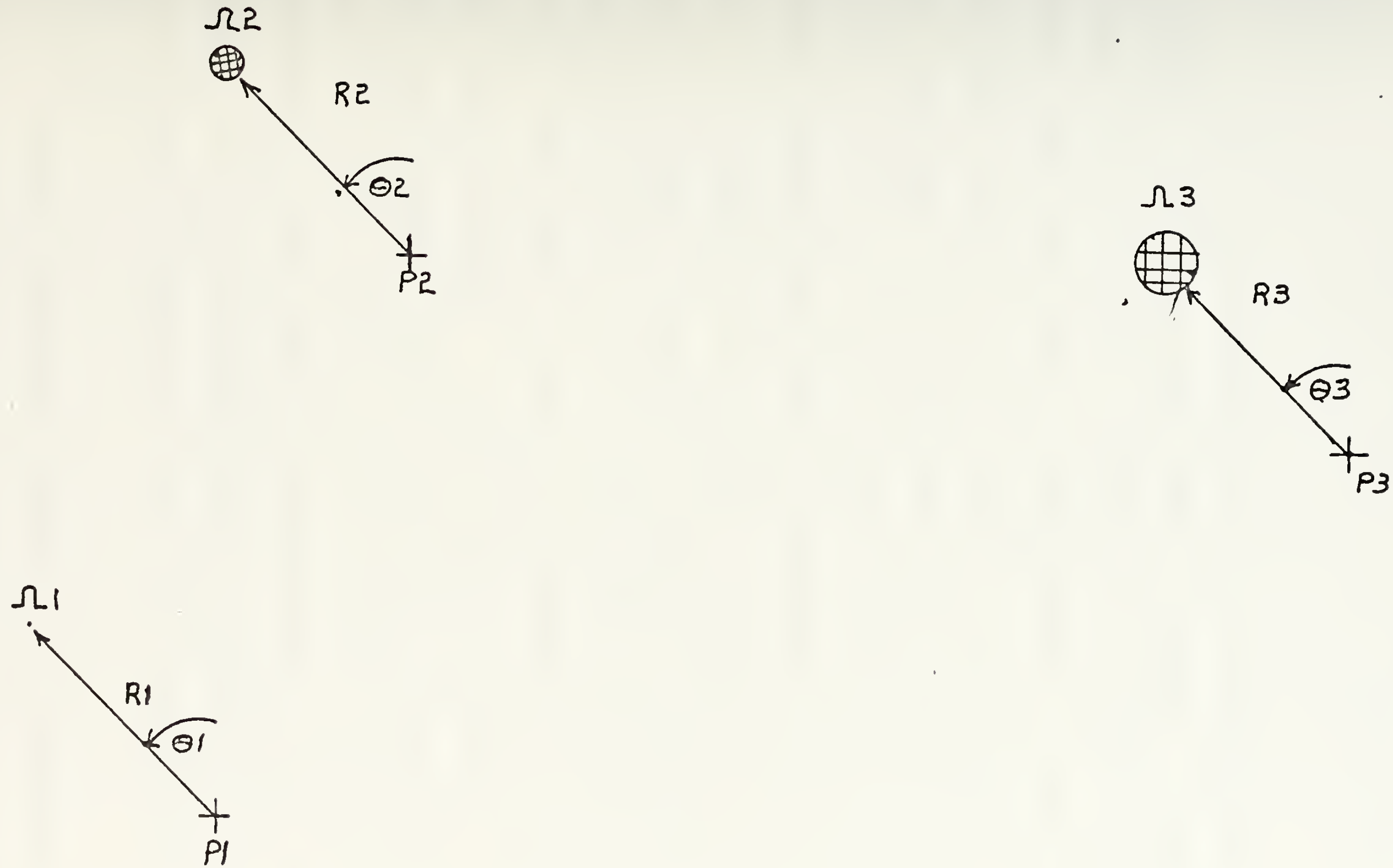


Figure 8
Uncorrected Omega Fixes about a Given Point

of the uncorrected Omega fix from the actual location in each case will be essentially the same, $R_1 \approx R_2 \approx R_3$ and $\theta_1 \approx \theta_2 \approx \theta_3$ within the limits of the anticipated error (.15 - .6 nm).

With this information, it is now possible to devise a relative position scheme that is capable of accurately fixing reported targets without use of TACAN or any transmitted signal from the aircraft carrier. Figure 9 shows the actual position of the aircraft carrier (P_1), aircraft (P_2) and target (T_1) along with their assumed positions, A_1, A_2, and TA_1. The aircraft's assumed position is derived by some fixing device other than Omega and shows a large error to dramatize the problem. In actuality this error could be large if the basic navigation system was not operating properly; at any rate after prolonged flight, four to five hours, it can be considered less than accurate than relative Omega. If the target's range and true bearing from the aircraft, and the aircraft's assumed position were relayed to the carrier, and the carrier used its assumed position A_1, the range R_1 and bearing θ_1 to the target would prevail. As can be seen from the depiction in Figure 9, this is in error as compared to the actual range and bearing, (R_2, θ_2).

If the uncorrected Omega fixes were used as references, the geometry of Figure 10 would prevail. The aircraft would report the same range and bearing, but

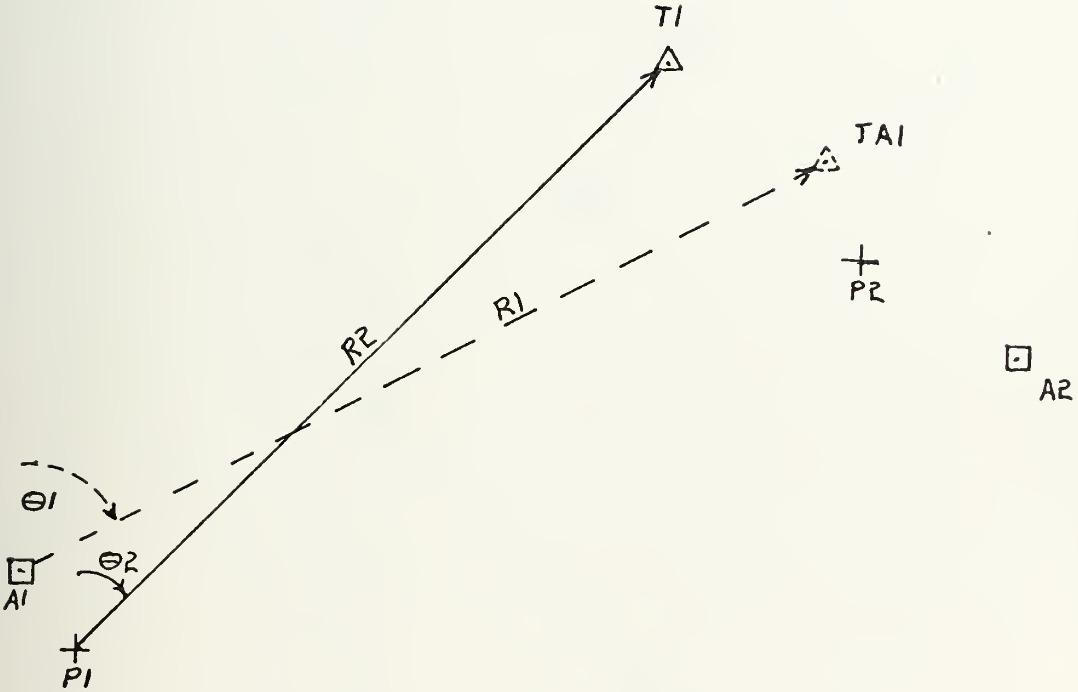


Figure 9

Range and Bearing Error Using Basic System Fixing Devices

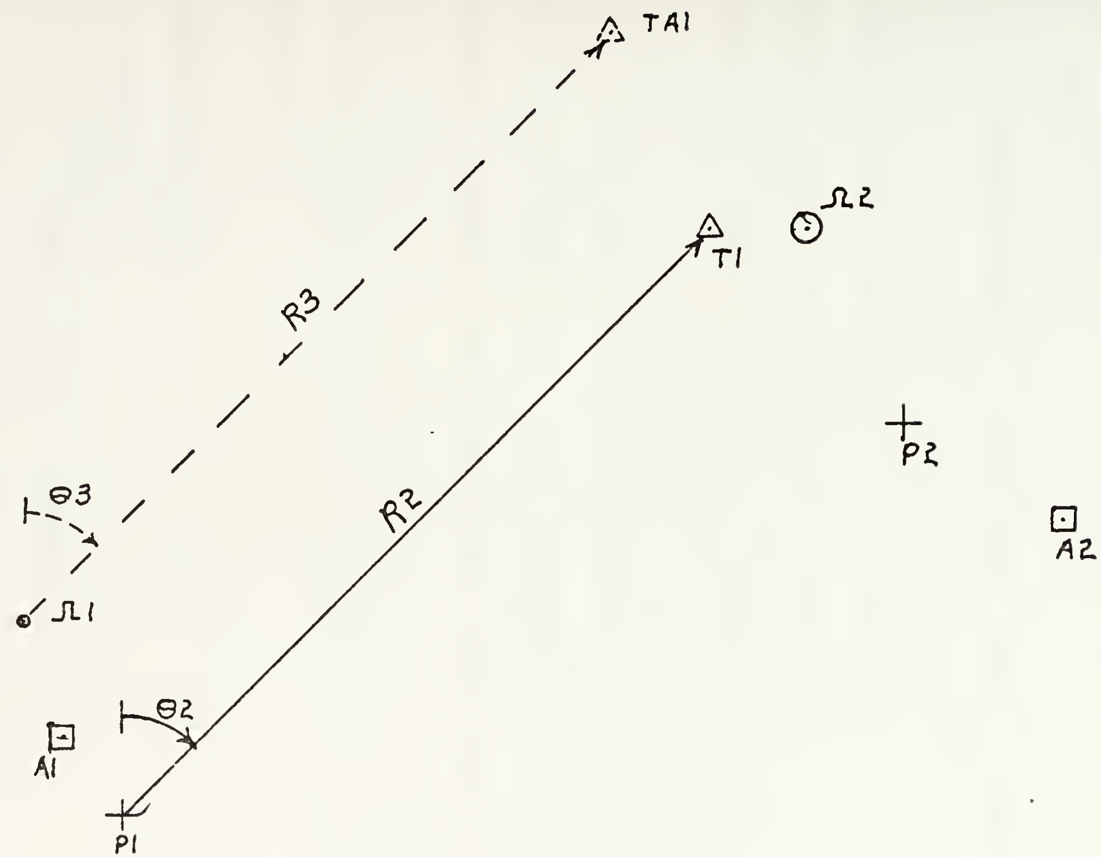


Figure 10

Range and Bearing Using Omega and Relative Fixing Scheme

instead of its assumed position, it would report the uncorrected Omega fix. The aircraft carrier would then apply its uncorrected Omega fix as a reference and the resultant, R_3, θ_3 would exist. This range and bearing is now within the limits of the relative Omega scheme (.15 - .6 nm) to ranges of 300 nm, and approximately equal to the actual range and bearing R_2, θ_2.

2. Implementation

A modification of the Omega receiving sets would be required to incorporate a relative Omega fixing scheme. Computation of the uncorrected fix information would have to be accomplished both aboard the aircraft carrier and the remote aircraft. This would require an algorithm within the computing device that would take the computed lines of position, prior to correction for diurnal phase corrections, and supply an uncorrected Omega fix. This information would then be incorporated on the data link system and relayed automatically to the carrier. Corrected Omega fix information would also be computed to supply the aircraft with an added navigation aid.

D. SYSTEM ANALYSIS

1. Advantages

a. Reliability and Versatility

An added fixing device aboard any aircraft enhances the navigation suite reliability. Omega would provide accurate world-wide fixing information. The rigors of computing position location, assuming loss of inertial

system, during transoceanic flights would not exist. During flight profiles bordering sensitive areas, an accurate cross reference to the basic TASES system would exist, and any loss or degradation in the basic system would not necessarily result in an aborted mission.

b. Relative Fixing Technique

Omega offers a means of providing accurate long-term relative fixing without any RF transmissions from the carrier. Using a relative fixing scheme as previously discussed, only the aircraft need transmit his uncorrected Omega fix. Target locations can be relayed to the carrier at accuracies approaching .15 - .6 nm within the relative area.

c. Position Keeping and Rendezvous

Error growth in inertial navigators is a function of time and Schuler oscillation, whereas Omega is dependent upon propagation variations. Two aircraft using inertial navigators could have errors in their positions that would exceed the limits for successful rendezvous. If these aircraft were both using Omega, they would experience the same propagation errors and thus their error in position would be a function of the accuracy of their respective Omega receivers. A typical Omega receiver is accurate within 1 CEC or approximately .16 nm, well within the limits for successful rendezvous.

2. Disadvantages

a. Vulnerability

Any RF fixing device is vulnerable to jamming or deception and Omega is no exception. Its only defense against these methods is its mode of operation and the dual purpose concept. Omega operates at 3 VLF frequencies. Any jamming device would require a fairly large transmitter and antenna system. It is not unlikely that the adversary would also use the system for navigation. Thus, by jamming the system he also loses his navigation aid.

b. Risks

Airborne Omega receiving and tracking systems are still in developmental stages. Operational testing has been accomplished on a few systems. Although the accuracy of the system has been projected to approach that of existing shipboard devices, the limited number of operating Omega stations has prevented conclusive results.

IV. BASIC TASES SYSTEM WITH DIFFERENTIAL OMEGA

A. OVERVIEW

The preceding system as discussed offered increased flexibility and reliability over the basic TASES navigation package. This system uses the same principle as relative Omega, but lends itself better to existing systems aboard the carrier. The main difference is that the reference is now the ship's best known position. This offers the advantage of not converting the relayed information to the ship's coordinate system since that function is automatically done on board the reporting aircraft.

Many mission profiles will be flown within 300 nm of the carrier, some of which will extend beyond the 200 nm TACAN range. Even those flights within the 200 nm TACAN range will be subject to the accuracy of the basic TASES system for emitter location since no TACAN update of the CAINS navigation system is available. By incorporating a differential Omega scheme, the position accuracy of the platform as referenced to the carrier would fall between .15 nm and .6 nm at all times and would extend to ranges greater than 250 nm. The accuracy degrades as the range is increased.

The Differential Omega System as conceived employs a monitor site of known geographical position. The site receives the Omega signals and computes the uncorrected

lines of position as shown in Figure 11. As is explained in the appendix of this paper, propagation variations of Omega signals about a local area are correlated in time and distance as opposed to being random. Therefore, two sites in the local area will experience essentially the same propagation variations from a given Omega station. The only restriction is that the receiving sites must be located at a great distance from the transmitting site. Figure 12 shows two sites, A and B; the propagation path to a user, at point A, will be approximately the same as to the user at point B. There will exist a radius about point A where the path propagation variations are essentially the same. By comparing the site position to the lines of position as derived from the Omega stations, correction factors for that particular time of day and locale can be computed for each station. This information can then be transmitted to users in that particular area. Very simple circuitry is incorporated on the Omega receiving set to automatically apply these corrections.

This concept is equally applicable to the moving monitor site such as an aircraft carrier. The ship's Inertial Navigation System (SINS) and the TRANSIT Navigation System would provide accurate fixing information for the carrier. From this information the propagation variations can be determined and the corrections transmitted from the ship to the aircraft.

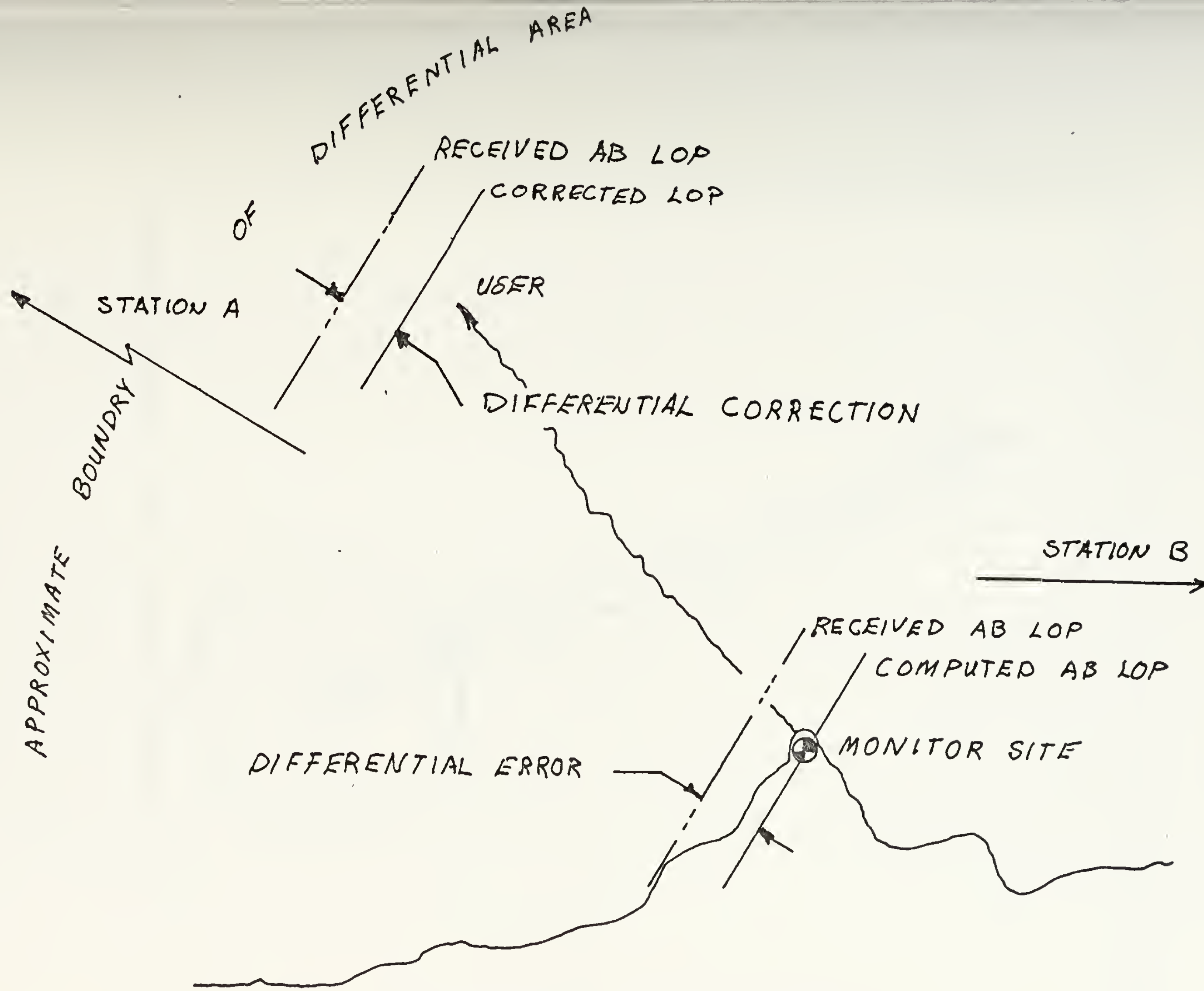


Figure 11. Differential Omega Concept

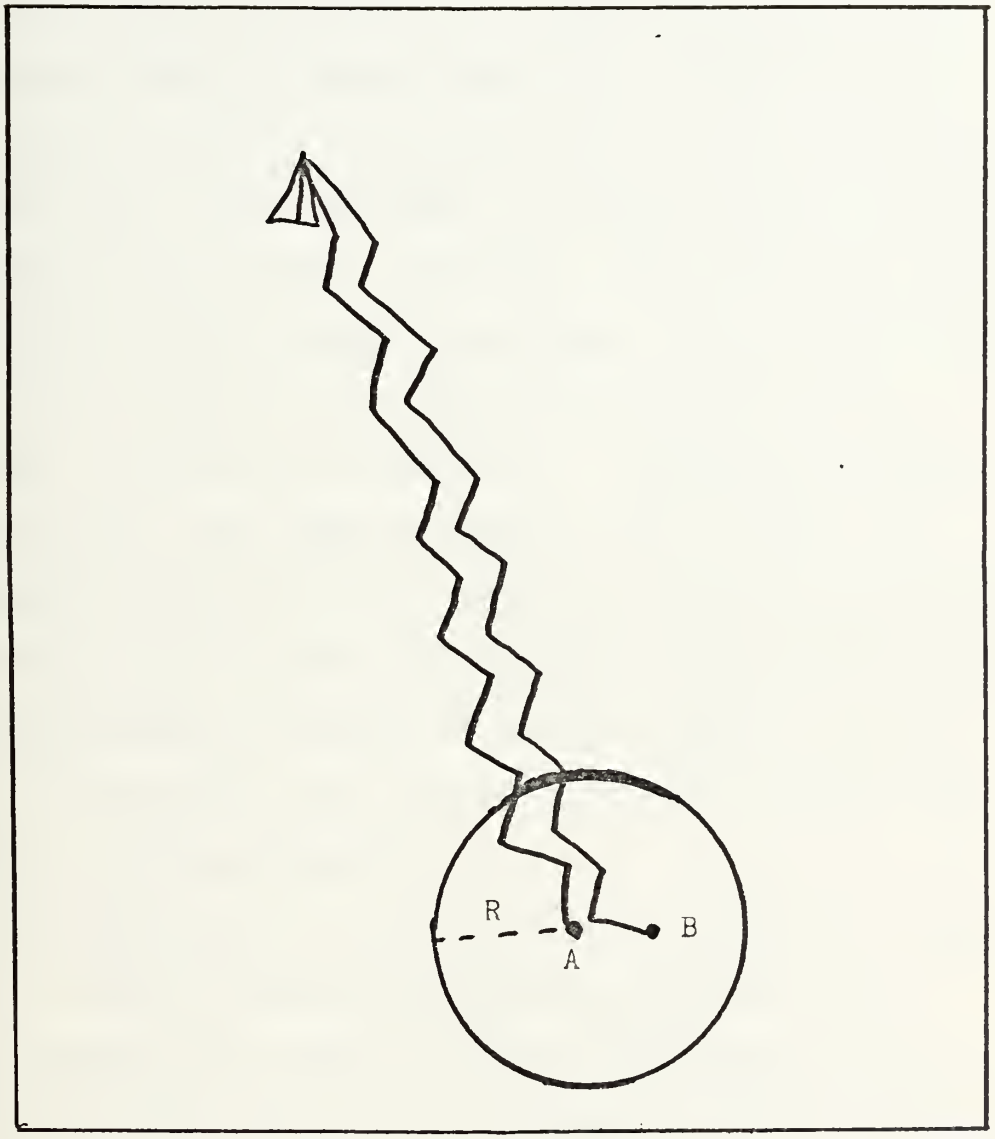


Figure 12. Omega Propagation Paths.

Of primary interest to the carrier is the location of its aircraft and hostile targets with respect to its position. For targeting information it would be desirable for reconnaissance aircraft to transmit position and DF information that is carrier referenced. That is to say the relative position of the aircraft in open ocean is more important that the geographical position when the aircraft is flying carrier support missions. For ranges up to 200 nm TACAN would provide relative position. Line of sight reception at this range would require the aircraft to be at altitudes in excess of 27,000 feet. Differential Omega could increase this range to greater than 250 nm, and by using HF frequencies for relaying correction information, no altitude restrictions would prevail. This would enable the reconnaissance aircraft to be more flexible in its mission profile and still provide continuous accuracy in position and DF information.

On missions that are not directly associated with the carrier, such as stand-off coastal surveillance, the system could be operated in the pure Omega mode as outlined previously. This would provide the pilot/navigator a backup system that has acceptable accuracies (1 nm daytime, 1-2 nm nighttime). This would enhance mission success in the sensitive areas that require accurate and continuous navigation.

B. PRINCIPLE OF OPERATION

Differential Omega as applied to an aircraft carrier as the monitor site would require very little added sophistication. By the time the TASES platform is operational, the Omega System will have been fully operational and many US Navy combatants will have Omega navigation capability. The transition to a differential Omega concept would be quite simple.

1. Proposed Differential Omega Systems

a. French System (Sercel Company)

This system uses a fixed monitor that compares the phase of the Omega signals to a local oscillator. These phase differences plus the phase of the reference oscillator are time multiplexed and are used to phase modulate a transmitter in the low HF range. The remote user has a correction receiver that is connected to the Omega receiver. So the signals are automatically corrected at the user site [Ref. 9]. See Figures 13, 14, 15 and 16.

b. Micro Omega (Teledyne Hastings - Raydist)

Omega signals received at the monitor site are converted to low frequency audio tones and phase locked to one of the incoming signals. Each tone is phase shifted a predetermined amount to subtract the monitor station's coordinates from the signal. This signal is now the correction for propagation variations. The tones are then transmitted on single side band HF frequencies. At

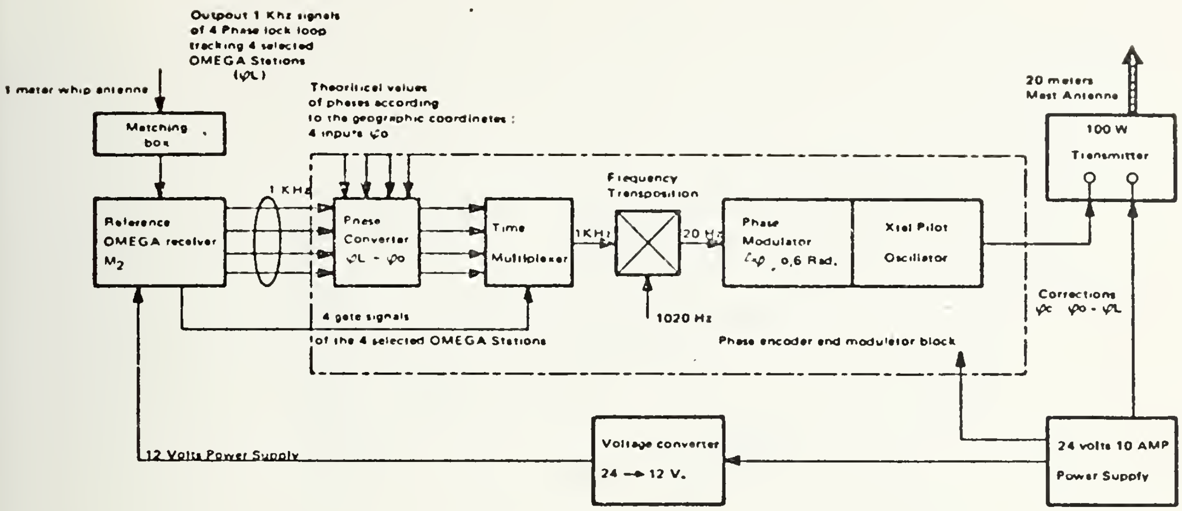


Figure 13. Sercel Differential Omega Transmitting Station.

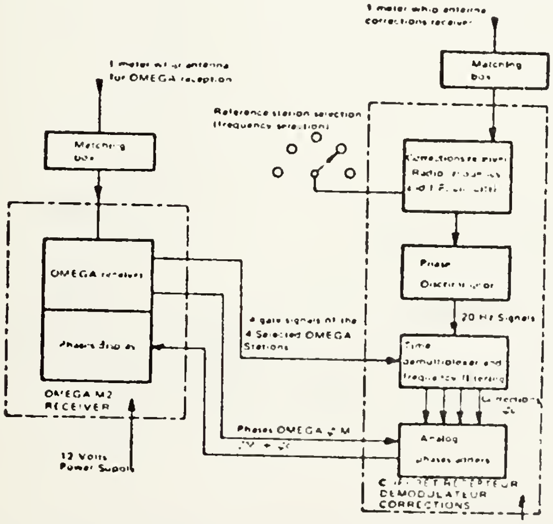


Figure 14. Sercel Differential Omega Receiving Station.

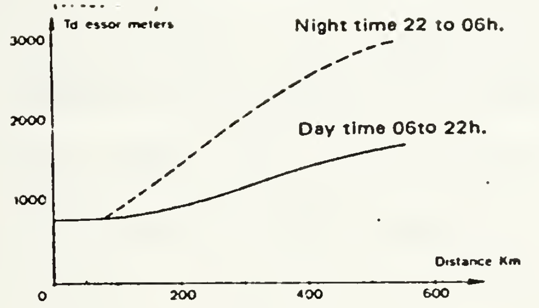


Figure 15. Sercel Differential Omega Test Accuracy.

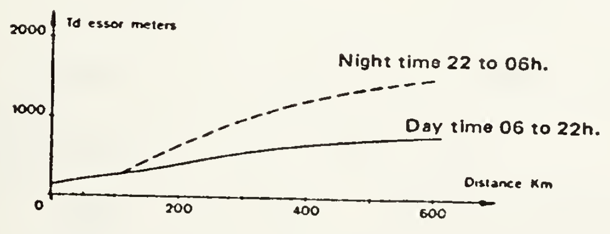


Figure 16. Sercel Projected Differential Omega Accuracy.

the remote site, the Omega signals are converted to low frequency audio tones and phase locked to an incoming Omega signal. The correction tones are then combined and applied to a phase meter. By comparing tones, phase difference readings are acquired to generate hyperbolic lines of position [Ref. 10]. See Figures 17 and 18.

c. Differential Omega Using Coast Guard Beacon

In this system the radio beacon acts as the monitor site. An Omega receiver and a differential Omega correction generator would be incorporated at the radio beacon. The corrections would take the form of an audio tone proportional to the propagation variation (Figure 19). An example of the correction tone spread would be:

Correction	Tone
+50 CEC	1500 Hz
+25 CEC	1250 Hz
0 CEC	1000 Hz
-25 CEC	750 Hz
-50 CEC	500 Hz

Continuous correction signals for four LOP's are transmitted in a predetermined format [Ref. 7].

d. Delta Latitude - Delta Longitude

This system would calculate the error in latitude and longitude between the monitor site and the uncorrected Omega fix. The site would then transmit a latitude and longitude correction to the users in the area.

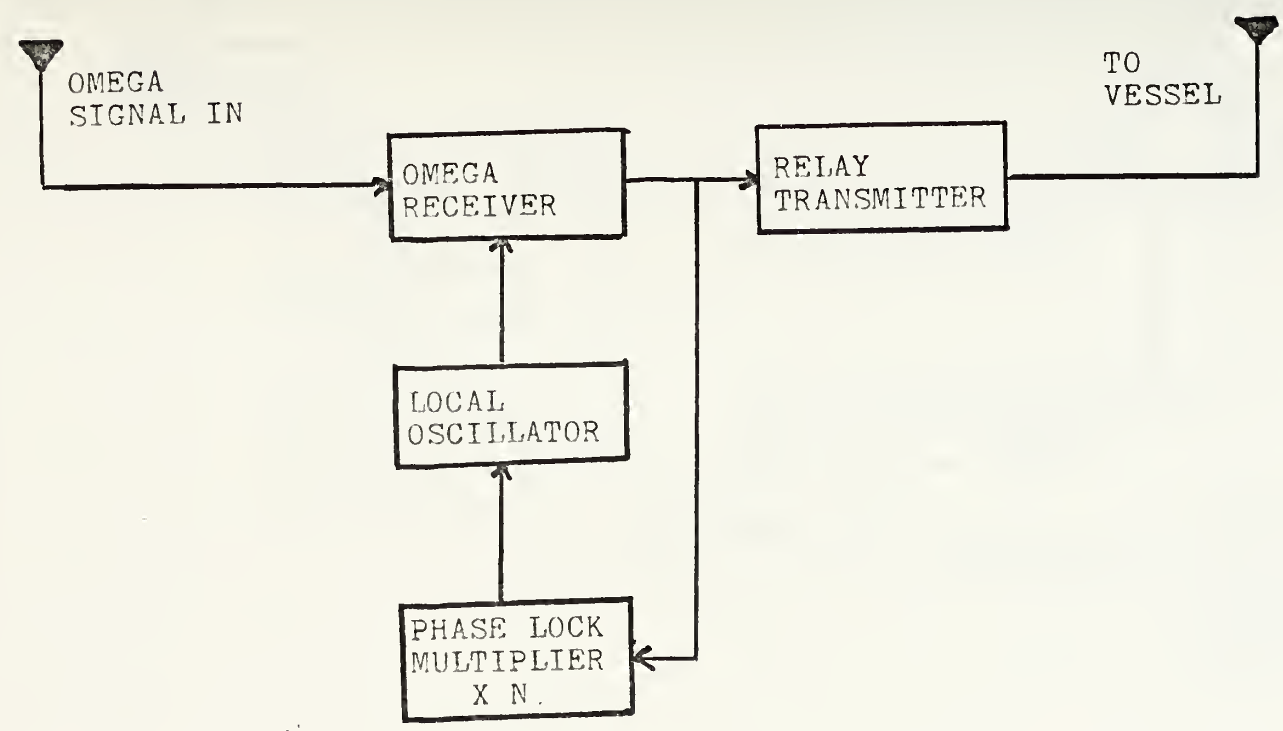


Figure 17. Micro-Omega Transmitting Station.

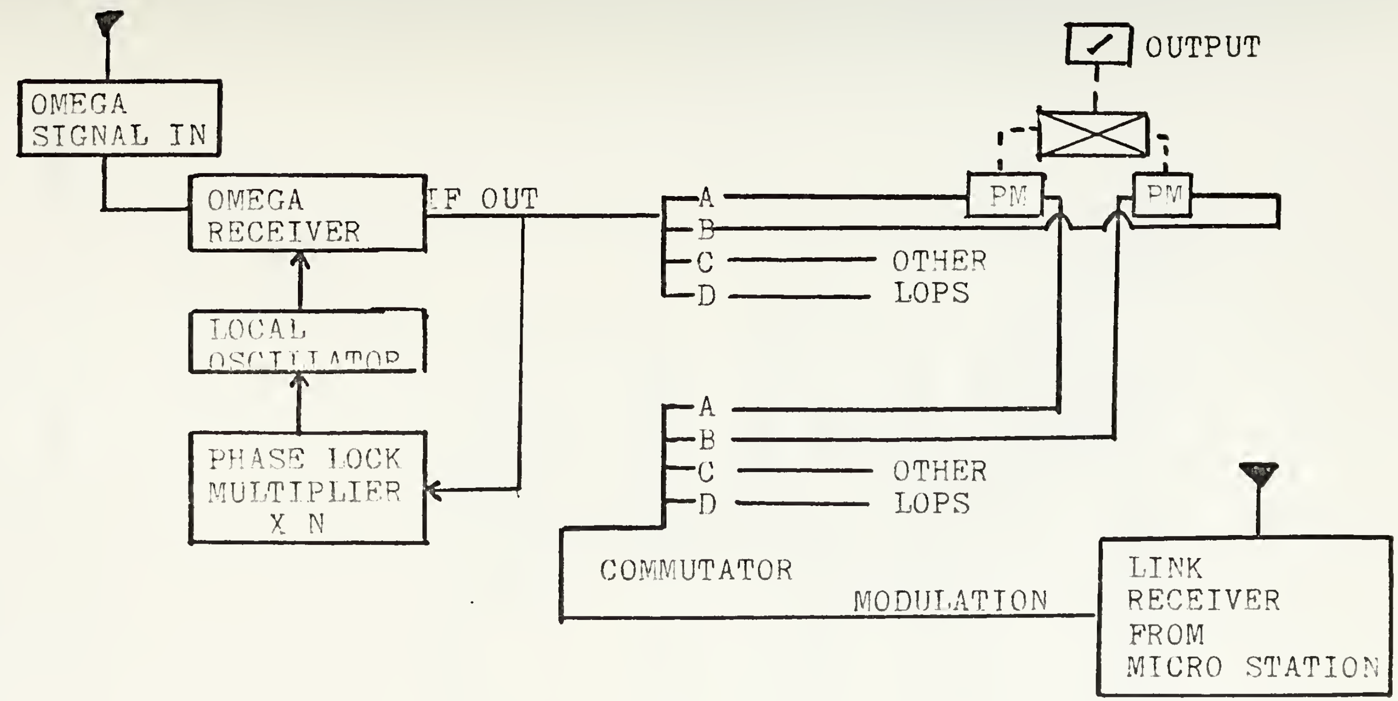


Figure 18. Micro-Omega Receiving Station.

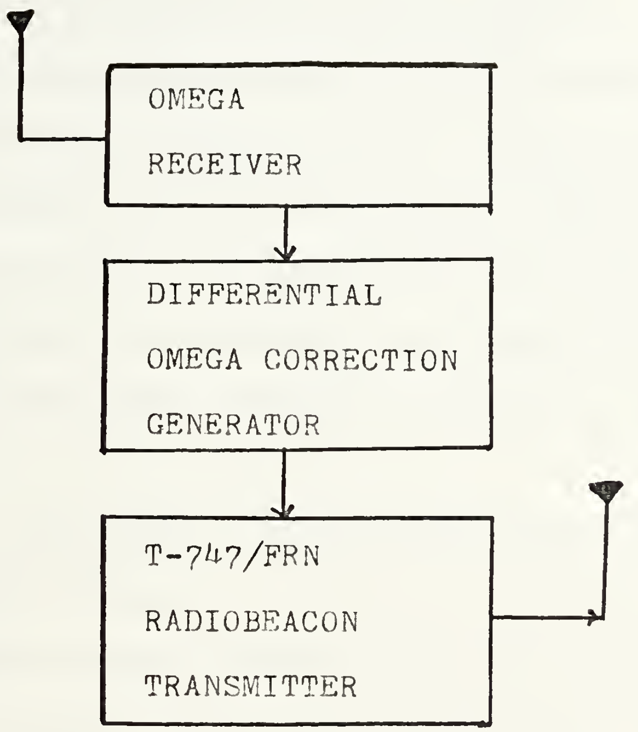


Figure 19. Differential Omega Transmitter Using a Coast Guard Radiobeacon.

This system though much simpler does not compensate for errors in the local oscillators; thus it is less accurate but still feasible.

2. Shipboard Differential Omega Scheme

Any of the above systems would be usable in a shipboard Differential Omega System. However, an automatic system would be most desirable for TASES since the pilot will also act as the navigator. Since the end result of all the systems is to provide corrections at the user site, only a Δ Latitude Δ Longitude scheme will be discussed in detail.

a. A Δ Latitude Δ Longitude Shipboard Differential Omega Scheme

The aircraft carrier will act as the monitor site in this scheme. Unlike the fixed monitor site there will exist some position errors relating to monitor site location. However, since the purpose of the system is to provide relative position, the geographical position errors are of little consequence. The carrier will be equipped with the same type of Omega receiver as is aboard the TASES aircraft. This will help compensate for any errors introduced by using different types of receivers and also provide conformity in the overall system. The receivers will be of the automatic type, such as the ARN-99(V)2, with the ability of supplying both uncorrected fix and corrected fix information in the form of latitude and longitude

read-out. Figures 20 and 21 show a block diagram of the monitor site system and the aircraft system.

The uncorrected latitude and longitude fix information that is derived from the receiver at the monitor site is routed to a difference network where it is combined with the latitude and longitude of the ship's best position. The ship's best position can be from any of its on board continuous fixing devices such as SINS, dead reckoning, satellite, or from the corrected Omega signal itself. If the corrected Omega fix is used, the delta latitude delta longitude of the precomputed propagation variation is transmitted. After the difference network the delta latitude, delta longitude correction is transmitted via data link signal to the aircraft.

The data link signal is then received aboard the aircraft, decoded and applied to the uncorrected Omega fix in the computer. The aircraft now uses this position when relaying target position or DF information.

If the data link is of high frequency design, no problem exists in transmissions beyond line of sight. However, if a UHF data link is utilized the approximate usable distance would be given by $d = 1.2\sqrt{h_1} + 1.2\sqrt{h_2}$ where h_1 is the altitude of the aircraft in feet, and h_2 is the height of the antenna aboard the ship in feet, and d is the distance in nautical miles. Thus an aircraft at 30,000 feet could communicate with a ship with its antenna at 100 feet at approximately 220 nautical miles.

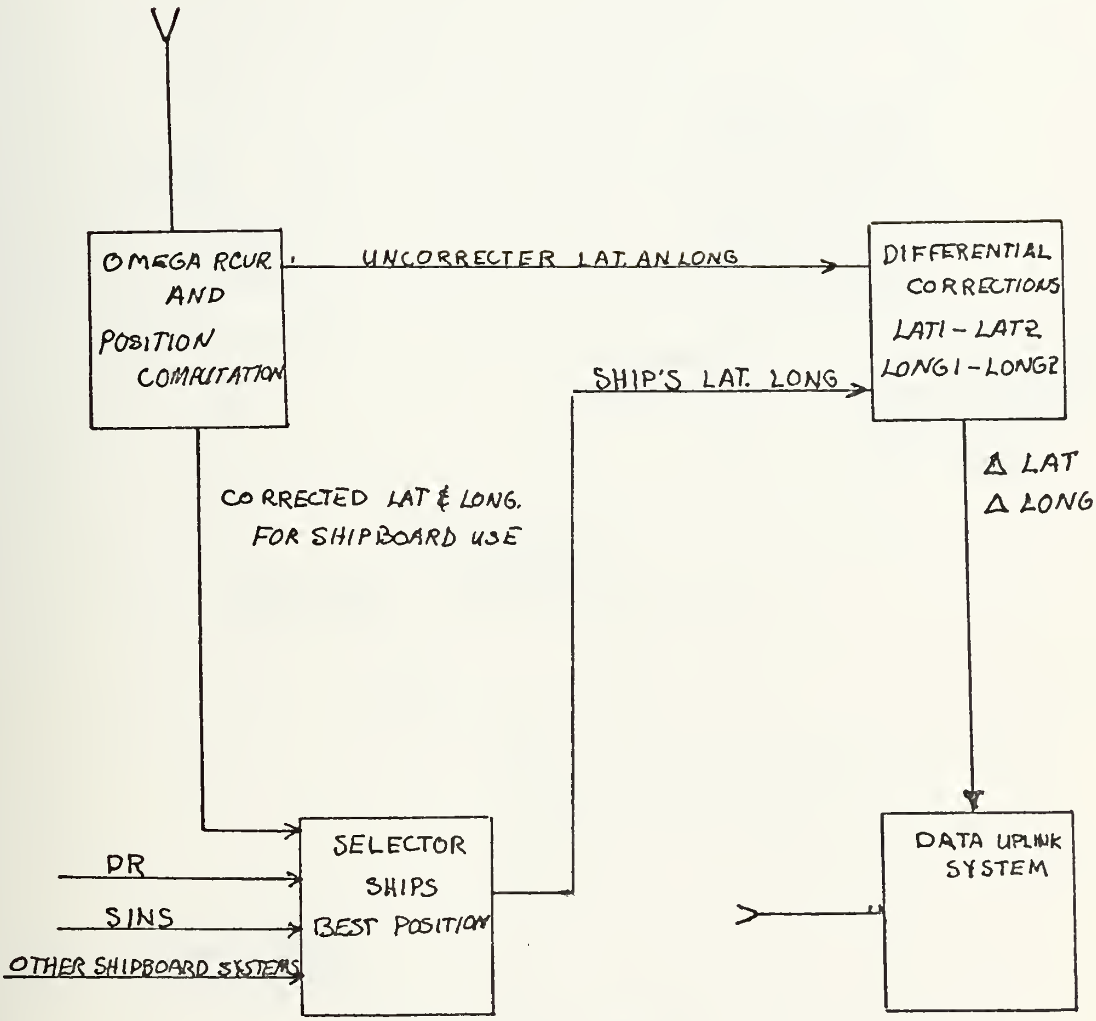


Figure 20. Diff. Omega Transmitting System

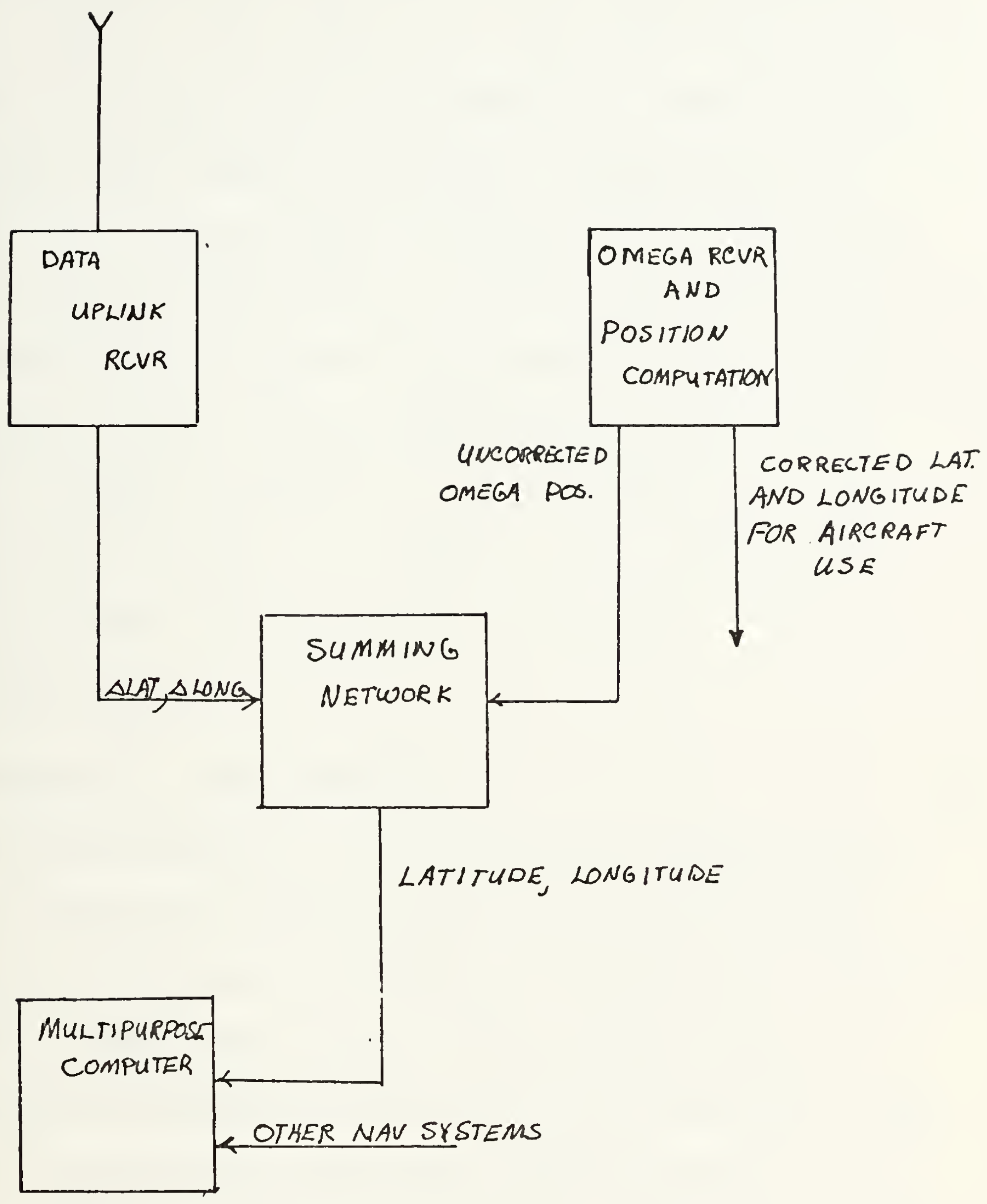


Figure 21. Aircraft Receiving System

an altitude restriction is placed upon the aircraft at any given range. If a relay data link was utilized between the E-S3 and carrier via the airborne E-2 then the range of the data link could be increased. Consider an E-2 at 20,000 feet, 170 nm from the carrier and the E-S3 on the same axis at 30,000 feet. In this case the E-S3 could communicate with the carrier at ranges in excess of 548 nm. This is much beyond the predicted differential radius. However, it may be feasible to use a Differential Omega scheme at these ranges. It remains to be shown experimentally if usable accuracies are obtainable at radii greater than 300 nm.

C. DIFFERENTIAL OMEGA GEOMETRY

The attractiveness of the differential Omega scheme is readily apparent when the geometry posed by the aircraft carrier and remote aircraft is considered. Figure 22 shows the assumed positions of the aircraft carrier and remote aircraft along with the actual and reported target position. In this case both the aircraft carrier's and the airplane's positions are in error. The actual range and true bearing of target from the carrier is R_1, θ_1. However, due to the error in actual position of both vehicles the carrier will determine from information passed to it by the aircraft that the target is located at a range R_2 and true bearing θ_2. It would be desirable to determine as closely as possible the actual range and

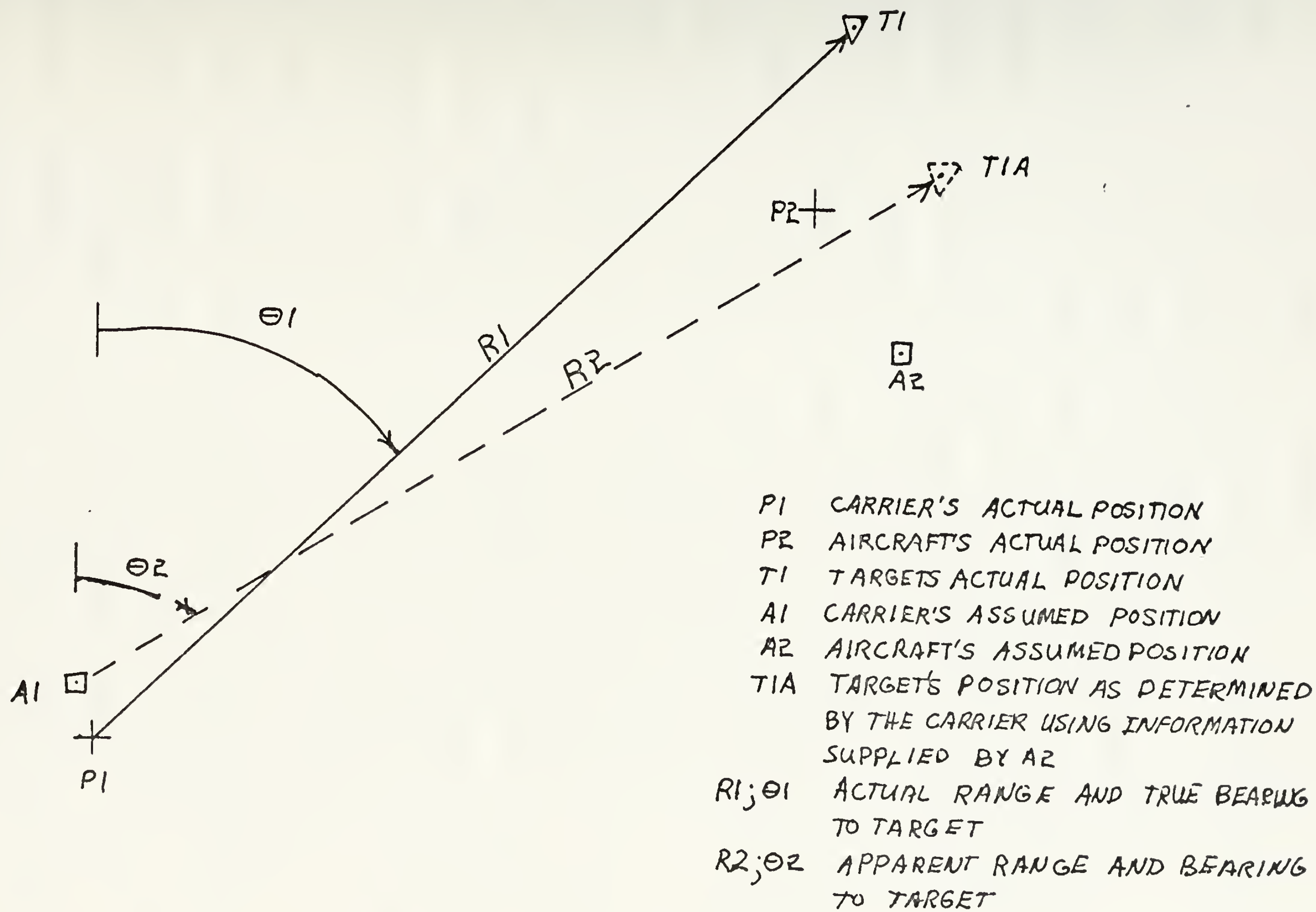


Figure 22
Range and Bearing Error Using Basic Navigation System

bearing of the target, regardless of the errors in actual position. This can be approached by referencing all positions to the aircraft carrier.

Because the amount of propagation variation is essentially the same in the differential area, the uncorrected Omega fixes will lie at approximately equal distances and bearings from the actual geographical positions. Looking at Figure 23, $R_1 \approx R_2$, $\theta_1 \approx \theta_2$. The approximation deteriorates as the distance between the two points increases. However, within 300 nm data has shown the fix errors fall in the range of .15 to .6 nm. Using this fact it is now possible to orientate the aircraft's position relative to that of the carrier. The delta latitude and delta longitude as derived from the uncorrected Omega fix to the carrier's assumed position is transmitted to the remote platform. These corrections are applied to the platform's uncorrected Omega position. The platform and aircraft carrier are now orientated at the same distance and bearing (within differential accuracy) from their actual fix positions. Now the problem of target location is attacked using Differential Omega. Figure 24 shows the actual and assumed locations of the aircraft carrier along with the assumed and actual location of the target. R_1 is the actual range of the target from the carrier and θ_1 is the associated true bearing. After the delta longitude corrections are applied to the aircraft's uncorrected Omega fix, its assumed position is moved to A_3.

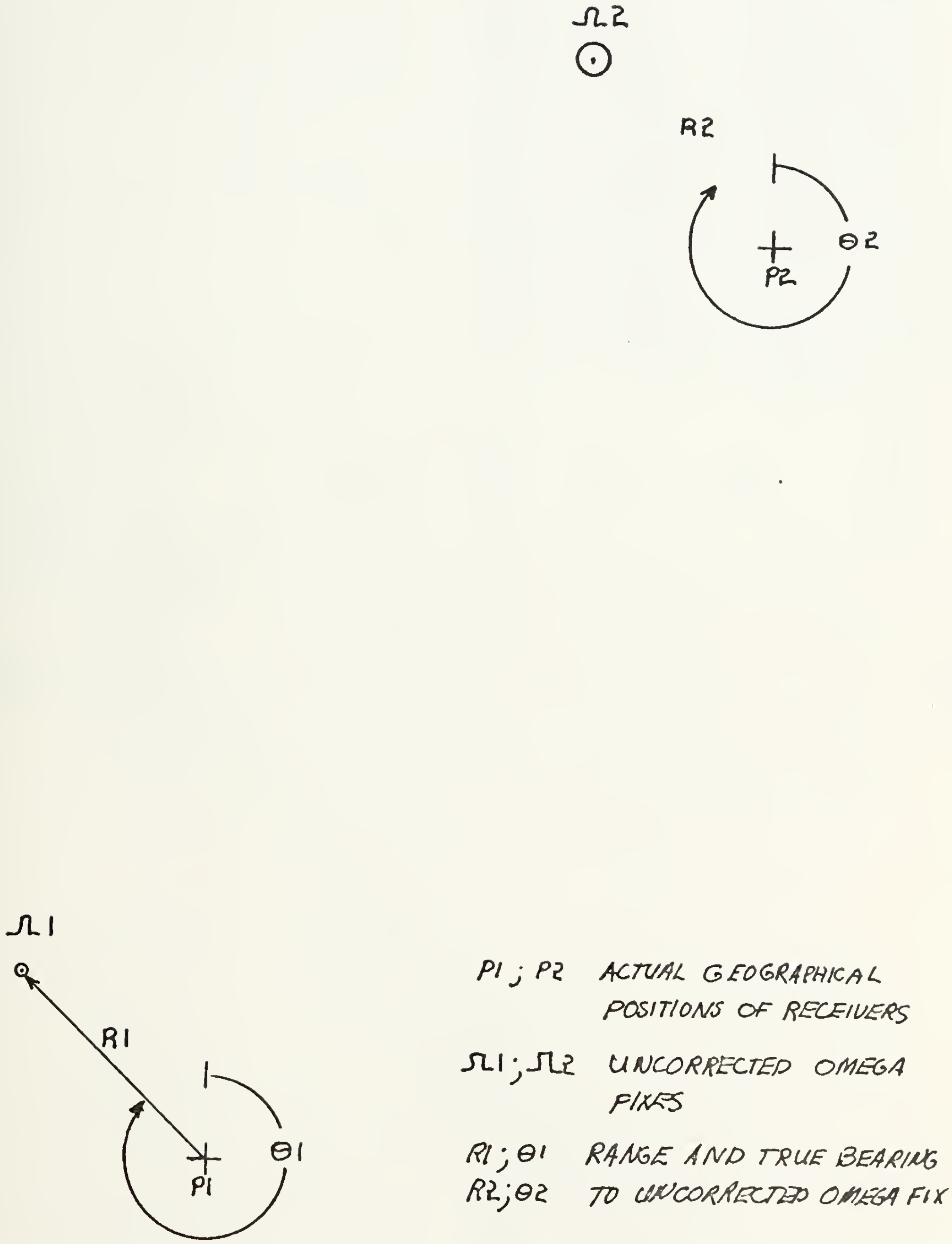
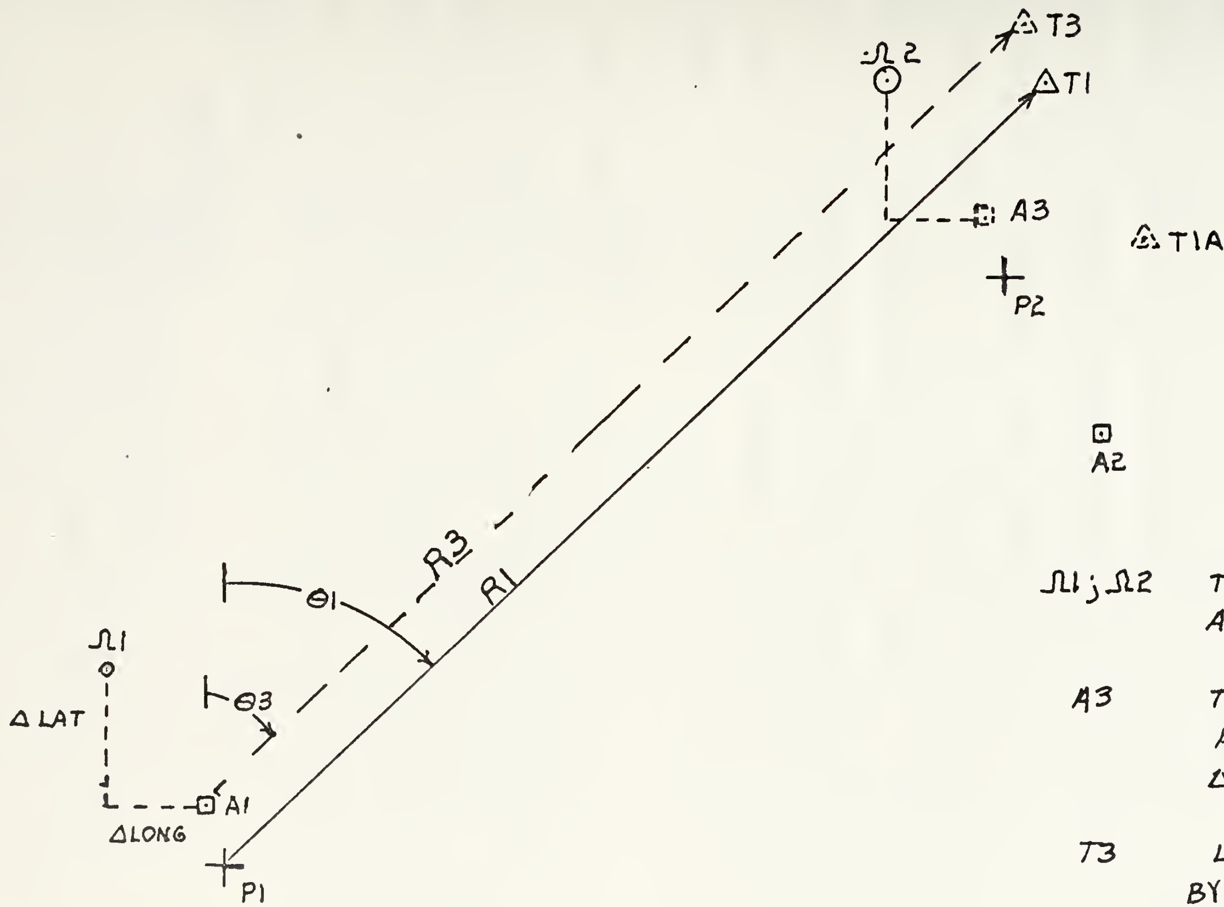


Figure 23

Range and Bearing from Actual Location to Uncorrected Omega Fixes



Ω1; Ω2 — THE UNCORRECTED OMEGA FIXES ASSOCIATED WITH P1 AND P2

A3 — THE ASSUMED POSITION OF THE AIRCRAFT AFTER APPLYING Δ LAT Δ LONG CORRECTIONS

T3 — LOCATION OF TARGET AS DETERMINED BY THE CARRIER USING THE INFORMATION SUPPLIED BY THE AIRCRAFT USING A3 AS ITS ASSUMED POSITION

R3; θ3 — RANGE AND BEARING ASSOCIATED WITH T3

Figure 24

Range and Bearing to Target Using Differential Omega

The target's true bearing and range remain the same from the aircraft, and only the aircraft's reported position changes from A_1 to A_2. The target's apparent location as interpreted by the aircraft carrier is now at T_3, and a new range R_3 and true bearing θ_3 are computed. Now within the accuracy of the Differential Omega scheme, $R_3 \approx R_1$ and $\theta_3 \approx \theta_1$. The actual range and bearing are approximately equal to the assumed range and bearing. The large error in the aircraft's position has been eliminated and its position relative to the carrier is within the differential Omega error. Small errors in the aircraft carrier's actual position are of little consequence since the carrier is concerned about the target location with respect to its apparent or assumed position. As long as the carrier knows its position within the lane width restriction (±36 nm for 3 frequency Omega receiver), this scheme is feasible.

D. SYSTEM ANALYSIS

The advantages and disadvantages of the basic S-3A Navigation Suite and the basic system with the addition of Omega has already been reviewed. The Differential Omega Scheme has a few additional pros and cons over the Pure Omega Scheme.

1. Advantages

a. Geographical Position

Unlike the Pure Relative Omega Scheme, the Differential System references the aircraft carrier's

best known location. By doing so both vehicles are using the best known geographical position. Although this is not important when referencing targets to the carrier's coordinates, it does decrease the confusion factor in working with two different fix locations.

b. Multipurpose Modes

In designing a shipboard Differential Omega System, it would be desirable to make the system compatible with any aircraft differential scheme that is designed ashore. It is likely that the Differential Omega System will be used by aircraft in the future. The increased accuracy offered by this system makes it a prime candidate for use in air traffic control areas, overland air routes, and airspace bordering coastal regions. Thus, if the shipboard differential scheme was designed to be compatible to any future aircraft land based scheme, a powerful navigation aid will have been added to the airframe.

c. Graceful Degradation

It is desirous of any navigation system to degrade gracefully. The Differential Omega Scheme fulfills this attribute. If the primary fixing device aboard the aircraft carrier(SINS) fails, another system such as the ship's dead reckoning systems or the ship's Omega system itself could act as the fixing device to compute the error signal to transmit. In the event that the data link system is not operating, the aircraft could go to a pure Omega mode and transmit its uncorrected Omega

information by some other means. The aircraft carrier could then reference all data to its uncorrected Omega fix as discussed earlier.

The addition of another on board fixing device also increases the reliability of the aircraft's navigation suite. Loss of the inertial navigation system and/or the doppler system would not place the aircraft in an unnavigable position.

d. Quick Reaction Time

In the event the aircraft must launch before the inertial system is aligned, the aircraft would have an accurate fixing device to accomplish its mission. Provisions could also be included in the design to supply Omega fix information to facilitate in-flight alignments, provided the aircraft has an operable doppler system.

2. Disadvantages

a. Weight and Space

Any aircraft design concerns itself with the weight and space problem. The addition of another navigation device would add to this problem. However, the relative gain in reliability and flexibility must be considered.

b. Vulnerability

Any system that relies on RF transmissions is vulnerable to jamming and detection. To operate in the differential mode, this system would require transmissions on the aircraft carrier's part. However, the system could work in the relative mode where only the aircraft would

transmit. In this case the aircraft would only transmit its uncorrected Omega position when it had other information of interest to relay to the carrier.

c. Risks

The Omega system is still in its infancy and there exists many problems to be solved. Although Differential and relative Omega are proven concepts there exists no operational data (other than testing and evaluation in limited cases) to substantiate a head first dive into aircraft system designs. However, the operational TASES concept is a few years away and during that time more information will be available to make the decision.

V. OMEGA - INERTIAL HYBRID

A. OVERVIEW

The Omega-Inertial Hybrid couples the short-term accuracy of an Inertial Navitation System to the long-term accuracy of the Omega System. During periods of Omega signal loss, the inertial system would provide accurate navigation parameters and maintain lane count until usable Omega signals were again received.

One proposed design would use a single axis inertial system coupled with an Omega receiver. Two and three axis systems are also feasible [Ref. 11].

B. OPERATION

Figure 25 shows a block diagram of a single axis Omega Inertial Hybrid. The one accelerometer is situated on a level platform as shown. Its alignment will coincide with the direction of the radio station being received. Thus the accelerometer will measure only the accelerations to and from the station. This signal when integrated would produce a velocity either to or from the station. The signal is then coupled through a servo into the navigation receiver and thus will maintain a fixed phase with respect to the received signal regardless of the motion of the aircraft. During periods of Omega signal loss the inertial system will correct for the position of the vehicle. An analysis of the system equations will not be dealt with

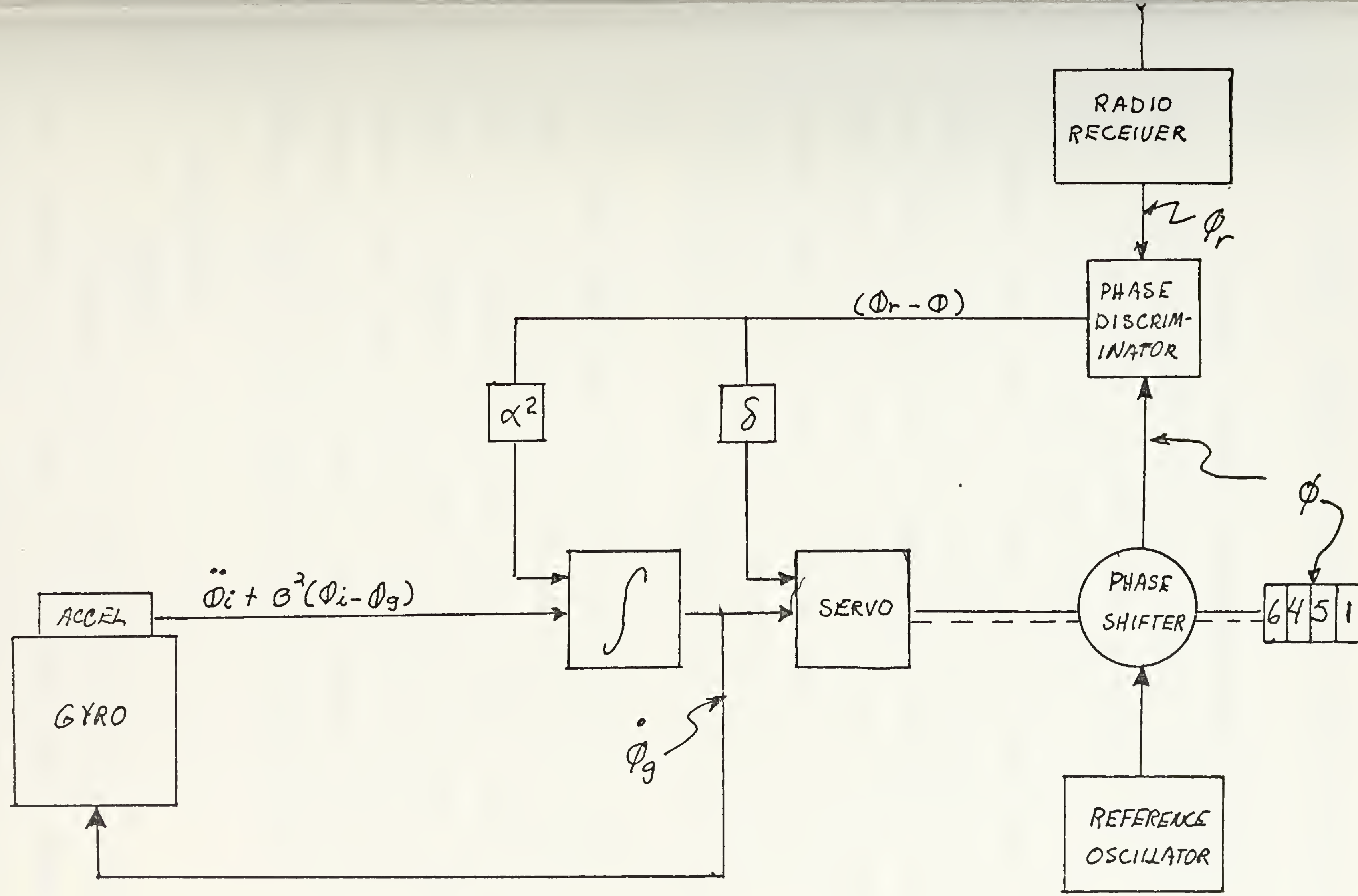


Figure 25
Single Axis Omega - Inertial Hybrid

in this thesis. Complete explanation can be found in Ref. 11.

In a multi-axis system the accelerometer could be aligned with different stations, whereby the filtered output of the inertial system would provide a more accurate acount of short-term maneuvers.

Whether the system is single-axis or multi-axis, the principal advantage of the system, when coupled with Omega, is a constant platform alignment, thus canceling long-term drift errors that would be associated with pure inertial. During short-term outages of radio signal, the pilot/navigator can be reasonably assured that his position error is slight and will only accumulate from the time of signal loss.

A most important feature of this system is that the inertial system need not be aligned prior to departure. Due to the feedback from the radio system, the platform could be aligned at any time as long as reliable Omega signals were being received. The time constant for alignment is of the order of eight minutes, and at 35 minutes there is less than 1% error in the system.

C. ADVANTAGES

1. Accuracy

The Omega Inertial Hybrid would operate within the accuracies of the Omega system when usable Omega signals are received. During periods of Omega signal loss

the system would operate within the accuracy of the inertial navigation system. The error, however, would accumulate from the time of signal outage rather than accumulating from initial alignment.

2. Alignment

Alignment of the inertial system prior to departure is not necessary. If usable Omega signals are being received the system can be aligned enroute and will provide accurate navigation within the time required for a normal inertial system to align.

D. DISADVANTAGES

1. Cost

Considerable design changes would be required of the basic TASES navigation system to implement an Omega-Inertial Hybrid. The principal reason for an Omega-Inertial Hybrid is to forego the expensive gyros and accelerometers that are used in aircraft inertial navigators. The CAINS system uses very accurate and expensive accelerometers and gyros. Thus any attempt to use this system with an Omega receiver would be defeating the purpose of the Omega-Inertial Hybrid design.

VI. CONCLUSIONS

United States Naval aircraft ELINT platforms in the past, such as the EC121 and EA3, have contained very rudimentary navigation devices. The primary fixing device for both these airframes has been a search radar system, and both aircraft had a dedicated navigator. Inertial navigators were introduced to the VQ community when the EP-3E airframe was made operational. The first inertial navigators installed in these airframes (Litton 102) proved to be very accurate but lacked good reliability. These systems were all replaced by a commercial inertial navigator (Litton 51); though less accurate, the system did exhibit better reliability. A dedicated navigator is also used on this airframe as it is common practice to cross-check the inertial system by taking periodic radar fixes. The airframe also contains a doppler/airmass, dead reckoning computer which was rarely, if ever, used because of its lack of long-term accuracy.

Navigation of the TASES aircraft will be unique in the Navy ELINT community. Airframes such as the EA-3, EC121, and EP-3E have dedicated personnel to act as navigators. TASES will place the navigation responsibilities upon the pilot. Successful and accurate navigation of the aircraft is dependent upon the reliability and performance of the CAINS system. The only back-up system for the pilot/navigator is the GPDC subprogram which is nothing

more than an elaborate digital dead reckoning computer. Radar checks on the performance of the inertial system and updates of the GPDC subprogram must be performed by someone other than the pilot/navigator. The need for an additional fixing device aboard the TASES aircraft is readily apparent.

Omega appears to be a logical choice for an additional navigation system. By the time TASES is operational Omega will provide world-wide navigation. Automatic tracking receivers would provide the pilot/navigator accurate and continuous navigation parameters at the touch of a finger, thus giving him the maximum amount of time to fulfill his primary duty of flying the aircraft.

A relative fixing scheme using Differential Omega or pure Omega could be incorporated to provide accurate target location. This scheme could also be extended to the NTDS system between ships at sea to provide accurate position keeping and targeting information.

APPENDIX A

OMEGA

A. SYSTEM DESCRIPTION

The Omega System is a radio locating device that will provide world-wide coverage using the VLF (very low frequency) spectrum. The global net will consist of eight transmitting stations located in the following areas: Norway, Trinidad, Hawaii, North Dakota, Reunion Island (Africa), Argentina, Australia and Japan. Full operation of the system is expected sometime in 1976.

1. Omega Geometry

The Omega system geometry is very much like that of LORAN and DECCA. The time difference of the arrival of two synchronized transmissions is measured, and a hyperbolic line of position representing an equal time difference is constructed. Omega arrives at this time difference by comparing the phase of the incoming signals.

In the proposed Omega system, the stations will be separated by approximately 5000 - 6000 miles. The hyperbolic lines between two stations will be lines of equal phase and will look much like straight lines when at great distances from either transmitter. Since the navigator should be able to receive at least five out of the eight stations, anywhere on the globe, there is no need to use relatively close stations for fixing purposes. Also,

considering such long base lines, "spherical excess" becomes an advantage since the sum of three angles of a triangle on a sphere can be considerably greater than 180°. Hence the ideal crossing angle (90°) of LOP's from two sets of stations can be more closely achieved.

With the use of eight transmitting stations for global coverage, usually five or six stations can be received. From these five or six stations, call them A, B, C, D, E, F, 10 or 15 lines of position can be obtained (i.e., AB, AC, AD, AE, BC, BD, BE, CD, CE, DE) for 10 LOP's from five stations, more than enough lines to get a reliable fix. The minimum number for a fix being two.

A 10.2 KHz signal will have a corresponding wavelength of approximately 16 nautical miles. This means every 16 nautical miles from the transmitting site the same phase will be measured (Figure 26). Thus between two stations, using a hyperbolic mode for navigation, the segments are reduced to eight nautical miles because the receiver is measuring phase difference from 0 to 180° between two stations. If the two stations were located 6000 nautical miles apart, there would exist 6000/8 = 750 lanes of equal phase, each eight nautical miles in width. Therefore the operator must know his position within ±8 nm to fix himself with a one-frequency Omega receiver. The lane widths are made larger by the transmission of multiple frequencies.

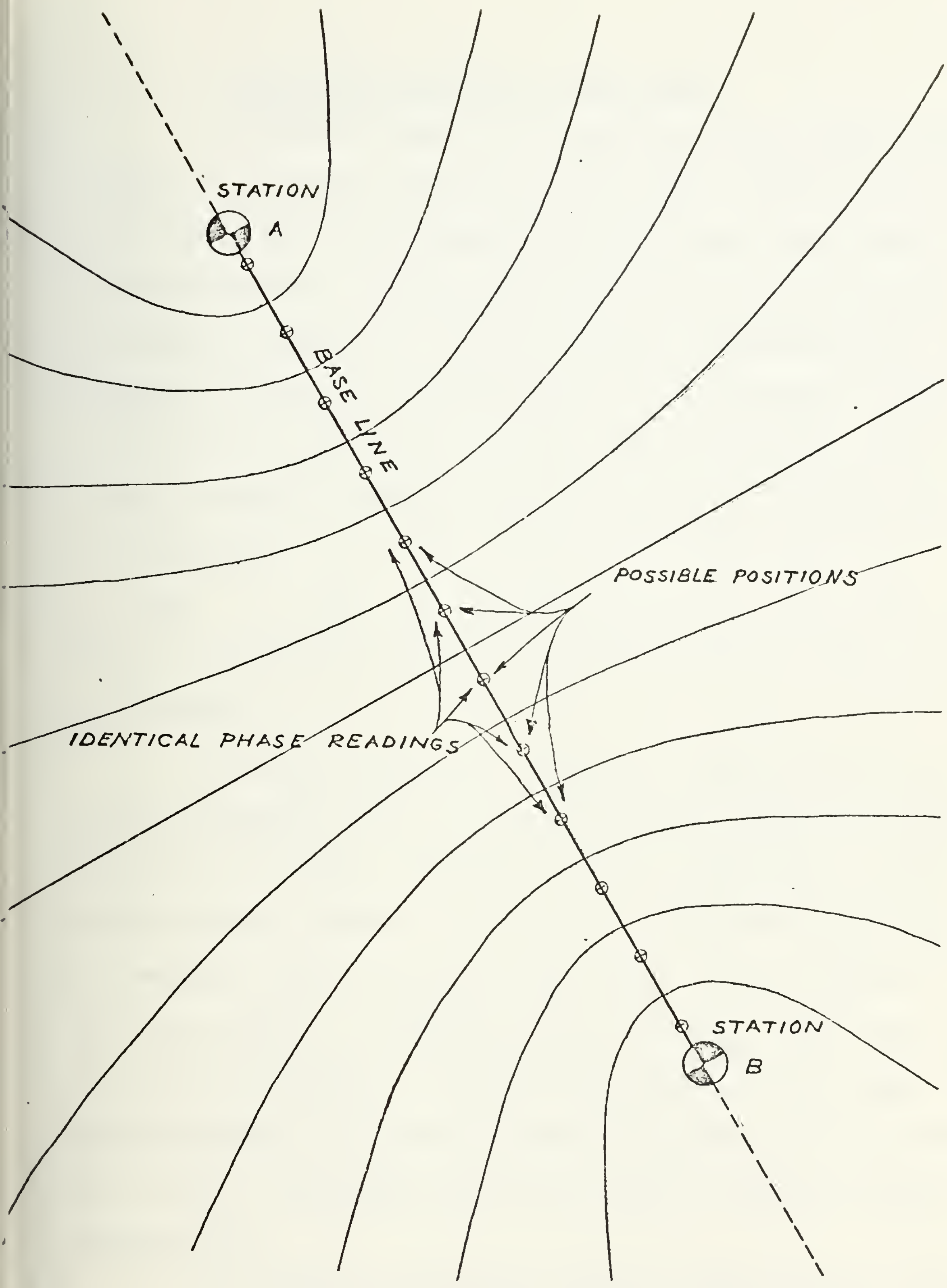


Figure 26
Base Line Lane Ambiguity

2. Transmission Sequence and Timing

The basic scheme for transmitting the Omega signals relies on only one station of the eight transmitting at any one time. Also the transmitted signal must have time to dissipate prior to the transmission of the next station. By using a delay of .2 seconds between transmissions, any residual fields in the wave guide are attenuated to such a degree to be unusable and thus non-interfering. The coding scheme for Omega's eight stations is as follows:

Station	H	A	B	C	D	E	F	G
Sec.	1.0	.9	1.0	1.1	1.2	1.1	.9	1.2

The .2 seconds gap appears between each for a total of 10 seconds.

The above code has a property whereby if it is cross-correlated with a unit correlating function at the receiver, a correct alignment will be indicated. In the above scheme, station A transmits a 10.2 KHz signal for .9 seconds, then .2 seconds dead time. Then station B for one second, .2 seconds dead time, etc. Since each of the eight stations is transmitting the 10.2 KHz signal for approximately one second in each 10 seconds, it is available for use the remaining 8/9 of the time to transmit other frequencies.

Two other frequencies will be transmitted in this time: 13.6 KHz, which will make the lanes three times as wide or 24 miles, and 11.3 KHz, which will further increase the lane width to 72 miles. (See Figures 27 and 28.)

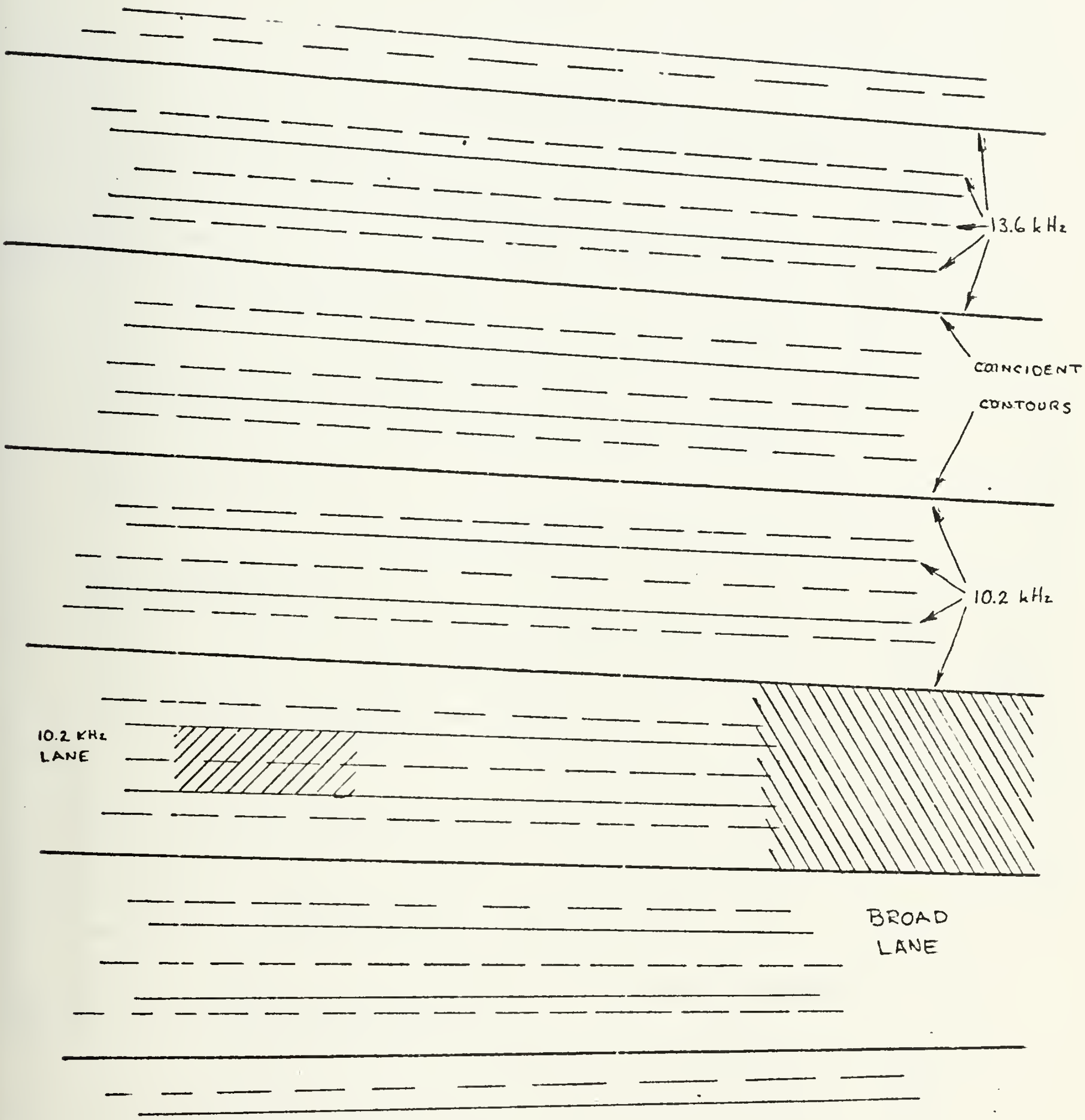


Figure 27
Two Frequency Lane Arrangement

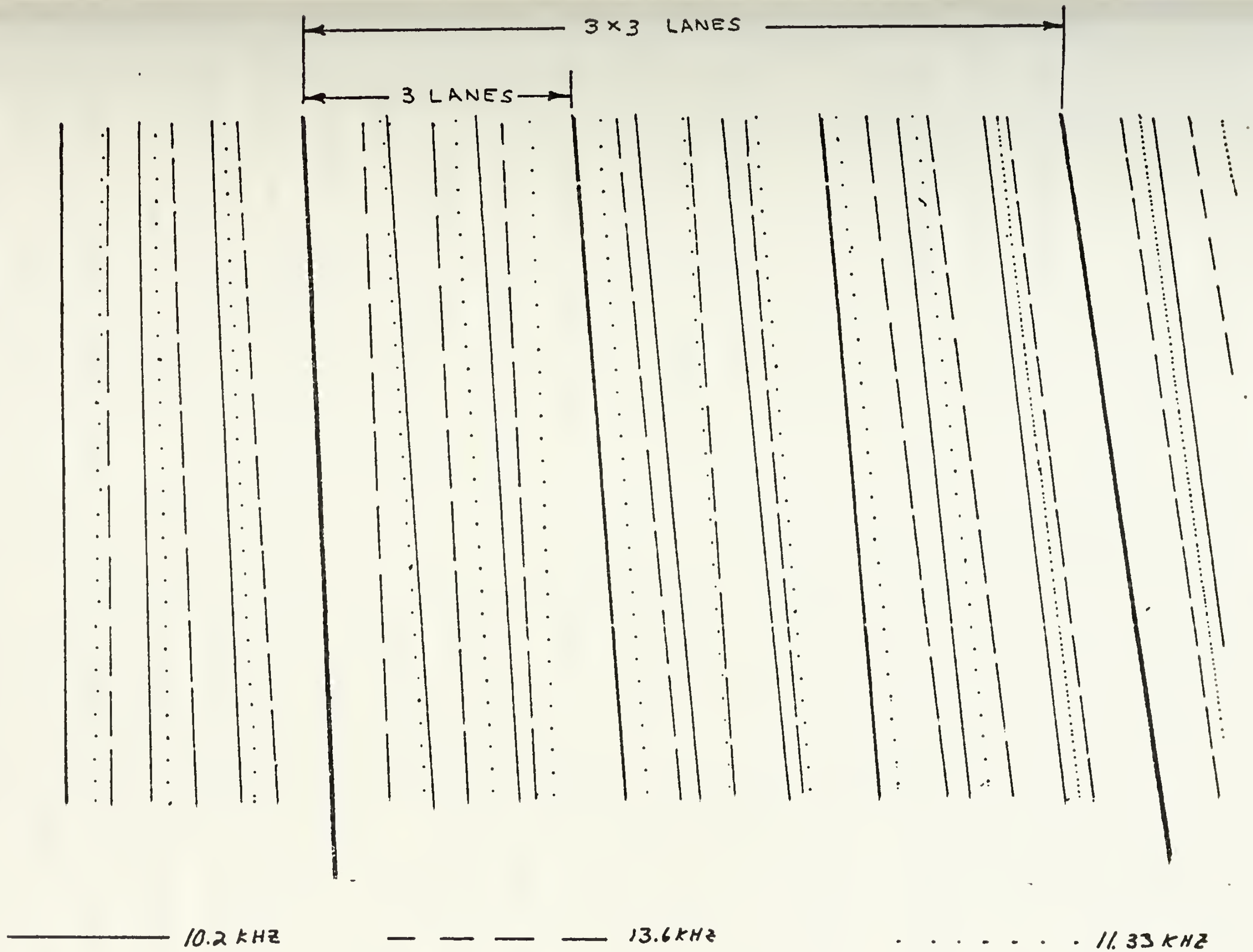


Figure 28
Three Frequency Lane Pattern

3. VLF Propagation

For the past twenty years much research has been done on the propagation properties of long wave radiation in the KHz region. The major interest is the small attenuation for these signals in the atmosphere. Usable signal levels for receivers have been recorded at over 9000 miles with reasonable power outputs at the transmitter. These low frequencies tend to follow the curvature of the earth; this phenomenon is caused by the spherical wave guide effect between the earth and the upper atmosphere.

At 40 KHz the first mode in the wave guide between the earth and upper atmosphere is very weakly excited and a second mode dominance may appear at some distance from the transmitter. Also temporal effects at this frequency can cause serious mode interference. When 20 KHz is used, the first mode is dominant, but during nighttime transmission the second mode is strongly excited (wave guide dimensions change along with velocity of propagation). Thus unpredictable phase variation occurs between night and day. When the 10 KHz signal was tested, the first mode was well excited and the interference between night and day was far less severe. However, the wave length is comparable to the height of the ionosphere, which causes increasing transmission losses. At 5 KHz the daytime signal is greatly attenuated and directional effects become quite large. Also the power required for radiation is much higher. Considering the

effects of each of the above frequencies, a signal of around 10 KHz was decided upon to have the best overall characteristics.

a. Propagation Variations

VLF propagation can best be described as being composed of various modes within a spherical waveguide structure between the earth and the ionosphere. Modal interference becomes less severe as the distance from the transmitting site increases. At distances greater than 600 nm, the TM_{01} mode is dominant and usable signals are obtainable. Many factors such as ground conductivity, latitude, earth's magnetic field, path bearing, season and solar activity can affect the propagation velocity of VLF waves. Many of these factors are predictable, and successful models have been developed to compensate for phase variations. Diurnal phase changes are caused by the variations in the height of the reflection layer in the atmosphere. The height of this layer remains fairly constant during nighttime or daytime propagation. Large variations do occur during the transition stages at sunrise and sunset.

Successful and accurate navigation using the Omega system is dependent upon the precise predictions for these propagation variations. At present the models can yield navigation accuracies approaching 1 nm daytime, and 1-2 nm nighttime.

B. DIFFERENTIAL OMEGA

Since the propagation paths are quite long in the Omega system (excesses of 5000 nautical miles are possible), the signal from an Omega station will experience essentially the same propagation variations when received at two different sites in the same general vicinity. Figure 29 shows two sites P_1 and P_2 located a great distance from an Omega station. The Omega signal traverses essentially the same path to each site. The lumped propagation variation of each path will also be essentially the same if the distance between P_1 and P_2 is small. Any unpredicted ionospheric disturbances between the sites and the station will have approximately the same effect on the received signals at P_1 and P_2. From this fact the differential concept has grown.

If P_1 was fixed, a value of the phase could be determined mathematically by using the undisturbed path. By comparing this value to the received signal the difference could be determined. The difference will be directly proportional to the amount of propagation variation the Omega signal experiences. This difference or correction could then be transmitted to other sites in the area where it would be applied to their received Omega signals. If this process were done continuously, the unpredicted variations would be eliminated as they occurred.

The maximum separation distances for P_1 and P_2 have not been fully determined. However, most investigators

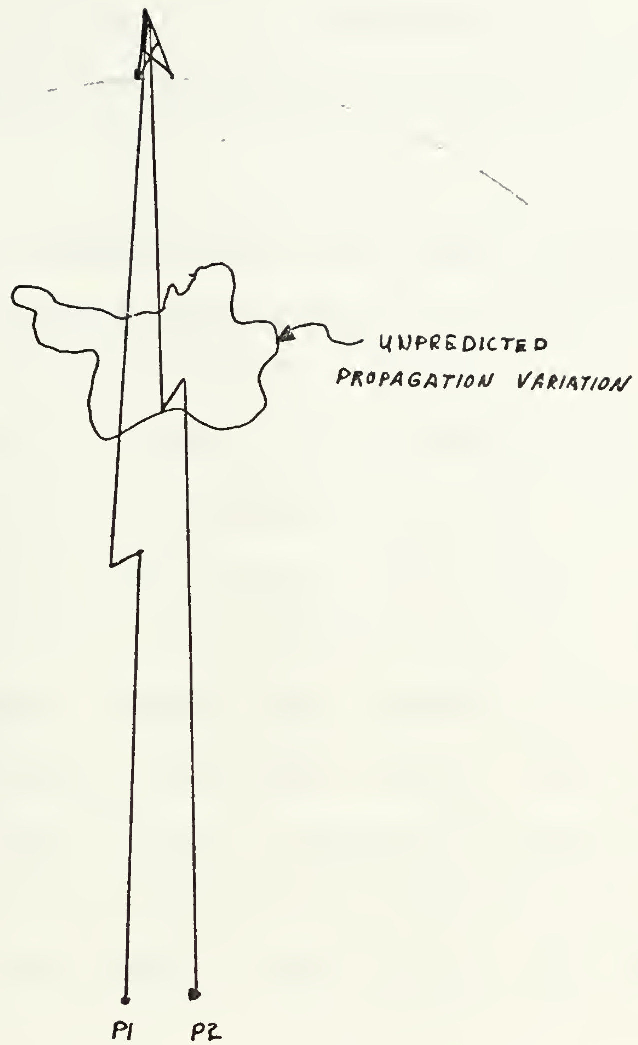


Figure 29

Omega Transmission Paths to Users
in the Same General Vicinity

agreed that 250-300 nautical miles is a good estimate that could yield accuracies of .15 to .6 nautical miles, the accuracy decreasing as the separation is increased.

C. RECEIVERS

Receivers for the Omega system can range in complexity from a simple oscilloscope representation of phase to a sophisticated Omega-Inertial Hybrid receiver.

Since the signals received occur at different times, some type of memory must be incorporated in the receiver to measure the relative RF phase between two stations. This is accomplished by having an internally generated continuous time base. Any typical receiver must perform the following functions: filter signal from noise; provide time multiplex; provide local time base for use in comparing phase; phase measuring circuitry that is capable of measuring with reasonable accuracy the phase of each signal with respect to the time base.

Operating in the above capacities, there are various ways in which the system can be used to achieve simultaneous tracking of two or more signals. It must be noted here, however, that regardless of the number of stations utilized, the receiver must keep track of the lane crossing or the navigator must know his posit within 8, 24, or 72 nautical miles (depending on his receiver complexity) or lane ambiguity will degrade his fix. Various receivers with differing capabilities are on the market today depending

on the needs of the individual user. For example, a basic one-frequency receiver might be adequate for a fisherman; however, the military may desire a three-frequency system capable of detecting the three Omega frequencies and a digital interface unit to compute position for a high-speed aircraft.

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